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SKYNET SGEMP TEST PROGRAM: THE SKYNET SATELLITE AS TEST OBJECT

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Ford Aerospace & Communications Corp.
3939 Fabian Way
Palo Alto, California 94303

December 1977

Topical Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The SKYNET I communications satellite was launched into synchronous orbit in 1969 as the keystone element of the United Kingdom SKYNET communications network. In 1974, the residual SKYNET I qualification model satellite became the keystone "real satellite" analytical and test specimen in the DNA-sponsored satellite SGEMP investigation program. Ford Aerospace provided the satellite, plus detailed information on the design and fabrication and assembly methods to co-contractors IRT, Mission Research Corporation (MRC), the Army Harry Diamond Laboratories (HDL), and

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20. ABSTRACT (Continued)

Pulsar Associates. Such details were used in a three-pronged effort: (1) IRT used the design details to establish computer code models of SKYNET, and these codes were used to predict SKYNET's SGEMP response; (2) HDL conducted current-injection tests to establish the structural and cable response characteristics; (3) low-energy x-ray irradiation of the satellite was conducted by MRC and IRT to: (a) validate the assumption that "tin-can" models can be effectively used to represent a real satellite for establishing satellite response; (b) demonstrate that the essential satellite response measurements can be made on an isolated satellite within a reasonable vacuum chamber; and (c) obtain the electromagnetic response of the satellite resulting from spacecraft charging. This latter investigation included both the spacecraft charging/discharging phenomenon alone and synergistically with x-ray radiation.

This report describes the analytical/test object, the SKYNET I satellite. Information related to the code predictions and the test results are available from the Defense Nuclear Agency, ATTN: RAEV.

PREFACE

We wish to acknowledge the direction and support on this Program received from LTC Mike Daley of DNA, who guided the program from its inception through the majority of the C-I testing, and LTC Ted Hawranick, who has so ably taken over the reins since Mike's re-assignment. Also, the program benefitted from the start from the participation of the associate contractors, including Eric Wenaas, Tom Tumolillo and Bob Keyser of IRT, John Rosado of HDL, Vasco Martins of XRI, Carlton Jones of Pulsar, and Vic Van Lint and Dave Fromme of MRC. Within WDL, appreciation is appropriate for the accomplishments of Tom Mattingly, Bill Diangson, Earl Cotterel, Art Wheeler and Carl Herington (plus the latter's several satellite handling crews). Finally, a special recognition is due to Jim Scharff of IRT/ Albuquerque, who more than anyone else on the program kept the several-company effort moving forward to and into the test sequence. His untimely death just prior to C-I test sequence 3 was a loss felt by the total program, as well as personally by all who had come to know him.

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1.0 INTRODUCTION AND SUMMARY

The SKYNET SGEMP Analysis Verification Program was initiated under the auspices of the Defense Nuclear Agency (DNA) in August, 1974. The Analysis Verification Program was to evaluate the adequacy of mathematical models of "real" satellites experiencing an SGEMP environment, and the success of computer codes, based on such models, in predicting the response of the satellite (structure, cables and other components) to this environment. The overall program made use of the SKYNET I qualification model satellite owned by the Western Development Laboratories (WDL) Division of Ford Aerospace and Communications Corporation, FACC (formerly Philco-Ford Corporation), as a "real" satellite to be modeled and as a test specimen to be tested, using current-injection techniques, to provide experimental data to evaluate the validity of the predictions of the computer model.

In the initial phase, the WDL Division supported the following team members (co-contractors of DNA) in carrying out the interrelated tasks which composed the SKYNET Current Injection Program:

a. IRT, which utilized the Ford Aerospace & Communication design data to establish codes, which then were used to predict satellite response to a variety of current-injection modes.

b. The U.S. Army Harry Diamond Laboratories (HDL), to whom was assigned the overall responsibility as test conductor.

c. Pulsar Associates, with an assigned responsibility to design and fabricate the current injection devices to be used to excite the satellite under a variety of current-injection modes called for in the mutually developed test plan.

In a follow-on phase, WDL provided support to Mission Research Corporation (MRC) in planning for and carrying out a series of Exploding-Wire-Radiator (EWR) photon tests. These MRC EWR tests began with simple geometry models to establish instrumentation and techniques, and culminated in EWR tests of the real SKYNET. The EWR testing was supplemented by an additional series of tests with an electron gun to simulate satellite charging in the natural plasma.

The WDL Division provided both the SKYNET I Satellite and satellite design/manufacturing/test expertise to all of the SKYNET SGEMP test team members. This included:

a. Support to IRT in establishing the computer codes. This included providing all the appropriate design details, as well as fabrication and assembly processes and standards, necessary to generate a representative computer model.

b. Participation with HDL and all of the other team members in planning the current-injection (C-I) test program.

c. Readying the satellite for the C-I test sequences in accordance with the test plan. This included changes to the satellite grounding system, adding of test points, removing components and substituting dummy boxes with provisions for selectable dummy loads, etc.

d. Designing and fabricating necessary handling and holding fixtures to be used to ship the satellite to the test site* at the Engineering Proving Grounds, Ft. Belvoir, Virginia, to hold the satellite during all C-I tests and to store it between tests.

e. Supporting HDL during all C-I tests. This included setting up the satellite on its special stand, removing and replacing solar panels and/or thermal shields to allow installation of stimulation and/or read-out equipment. WDL on-site personnel also assisted HDL personnel in establishing a workable overall test configuration.

*The Facility for Research of Electro-Magnetic Effects, or the FREME Building.

f. Support to MRC in establishing the critical satellite design/fabrication details so important for the EWR test planning. This included fixturing necessry for setting up and positioning the satellite in the AFWL 12-foot test chamber/OWL-II facility at Physics International (PI).

g. Supporting MRC during the EWR tests at PI. This included the installation of a variety of sensors, optical transmitters, switches, battery packs, etc. on and within the satellite. Continuing support was provided throughout the PI EWR and electron charging experiments to perform daily battery changes and occasional sensor reconfiguration.

This report will describe the SKYNET I Satellite in general (and relate it to other satellites), and the SKYNET I qualification model (the SGEMP test specimen) in particular. This description will include the changes made for this test program and the fixturing designed for holding the satellite.

For a complete description of the overall SKYNET Program, the reader is refered to a series of papers given at the AEC/DNA TREE/SGEMP Symposium held at Los Alamos, New Mexico, on 14-17 January 1975 (see References 1-6) and to the companion SKYNET Program Reports (References 7-10).

2.0 SKYNET I SATELLITE

The SKYNET I Satellite was a military communications satellite designed and developed by Ford for the United Kingdom (UK) under a contract administered by the USAF Space and Missiles Systems Operation (SAMSO). The UK SKYNET Communication system was the satellite portion of the United Kingdom Defense Communications Network. The system consisted of three fixed land stations, one shipborne station and one mobile land terminal with communication links to/from other stations via the SKYNET I Satellite. The original plan called for one SKYNET satellite, with a second satellite to be used as a backup. The system had an expected three-year life. The operational aim of the SKYNET Communication System was to provide long distance strategic point-to-point digital communications and to meet selected tactical communications needs. The satellite antenna pattern was designed for coverage from the United Kingdom in the West to Singapore in the East. Reference 10 contains the Proceedings of a SKYNET meeting held in London in April, 1970, at which 27 papers were given on the SKYNET program.

2.1 Description of the SKYNET I Satellite.

2.1.1 Mechanical Description. An artist's concept of the SKYNET I in orbit is shown in Figure 1. It is a spin-stabilized satellite with a cylindrical main body 137 cm (54 inches) in diameter and 81 cm (32 inches) high. A mechanically-despun, directionalized X-band antenna projected from the top and an exhaust nozzle for a solid-propellant apogee kick motor (AKM) protruded from the bottom. The total height of SKYNET, from the tip of the antenna to skirt edge of the AKM, was 157 cm (62 inches). At the top, grouped symmetrically around the despun X-band antenna, were UHF telemetry monopole antennas. The cylindrical portion of the body, which was covered by 7236 n-on-p solar cells, was spin stabilized at 90 rpm. SKYNET I in Geostationary Orbit weighed 127.4 kg (284 pounds).

The satellite structure is made up of a central load-bearing aluminum cylinder from which 8 equipment panels are supported by aluminum cylindrical struts. A secondary low-weight fiberglass structure is used to "hang" the 16 aluminum honeycomb solar panels from the main cylinder.

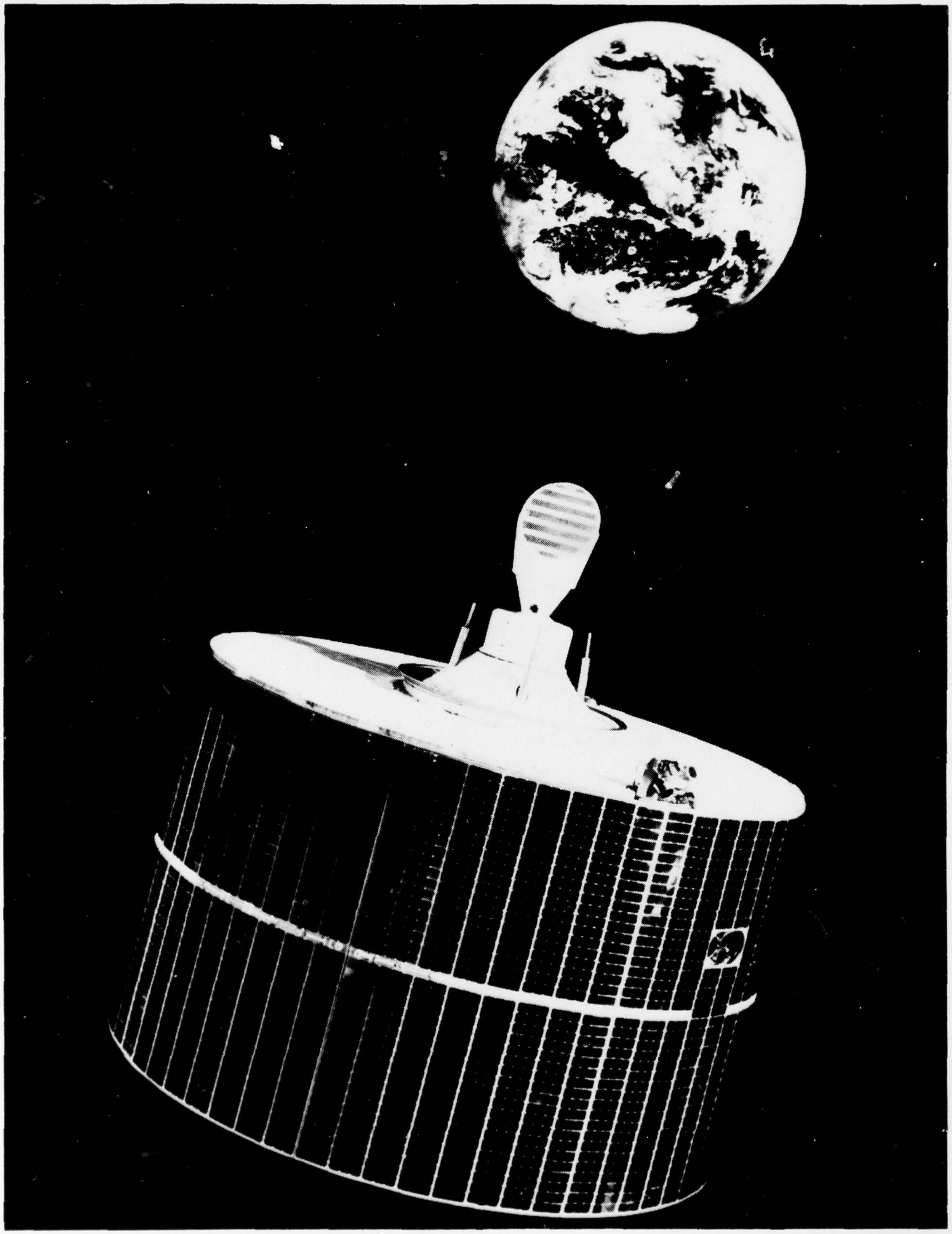


Figure 1 SKYNET I In Orbit

Figures 2 and 3 show the location of the solar panels, equipment platforms, and central cylinder. In Figure 4, which shows the satellite with solar panels removed, one can clearly see the central cylinder, the tubular support of the equipment panels (2 such panels are shown), and the light-weight secondary structure. Finally, Figure 5 shows the satellite, with the thermal panels removed so that the primary and secondary structures, equipment panels, and cabling can be seen.

2.1.2 Communication Electronics. The main function of the communications subsystem was to receive, translate in frequency, amplify, and retransmit X-band signals. Traffic requirements were telegraphy, speech and medium speed data (2400 bits/second). SKYNET I was the first satellite communications system to provide an all-digital mode of operation by employing Code Division Multiple Access (CDMA). For the 20 MHz bandwidth channel, CDMA multiplexing was chosen because the critical data utilized this channel. In the 2 MHz bandwidth channel, Frequency Division Multiplex Access (FDMA) was employed because no critical data passed over this channel.

SKYNET's operating frequencies are shown below:

	2 MHz Bandwidth Channel (MHz)	20 MHz Bandwidth Channel (MHz)	Beacon (MHz)
Uplink	7976.02 to 7978.02	7985.12 to 8005.12	
Downlink	7257.30 to 7259.30	7266.40 to 7286.40	7299.5

The SKYNET I design made use of redundancy to increase reliability and operational lifetime. The X-band repeater operated between 7 and 8 gHz using two channels to provide the main communication functions. Redundant 3.5-watt Traveling Wave Tube final amplifiers were coupled to the despun antenna to yield an output Effective Radiated Power (ERP) of 44.4 dbm. The despun X-band 19^{o} beamwidth antenna provided a gain of 18 db in the center of the beam, and 15 db within 9.5 degrees on either side, which was an order of magnitude greater than the output signal from earlier Military Communication Satellites. The communication system featured dual Intermediate Frequency amplifiers of 2 and 20 MHz bandwidth. Each bandwidth had two channels to handle simultaneous traffic separately and on a non-interference basis from both high-powered (High ERP antenna) fixed ground stations and low-powered (limited ERP) mobile terminals.

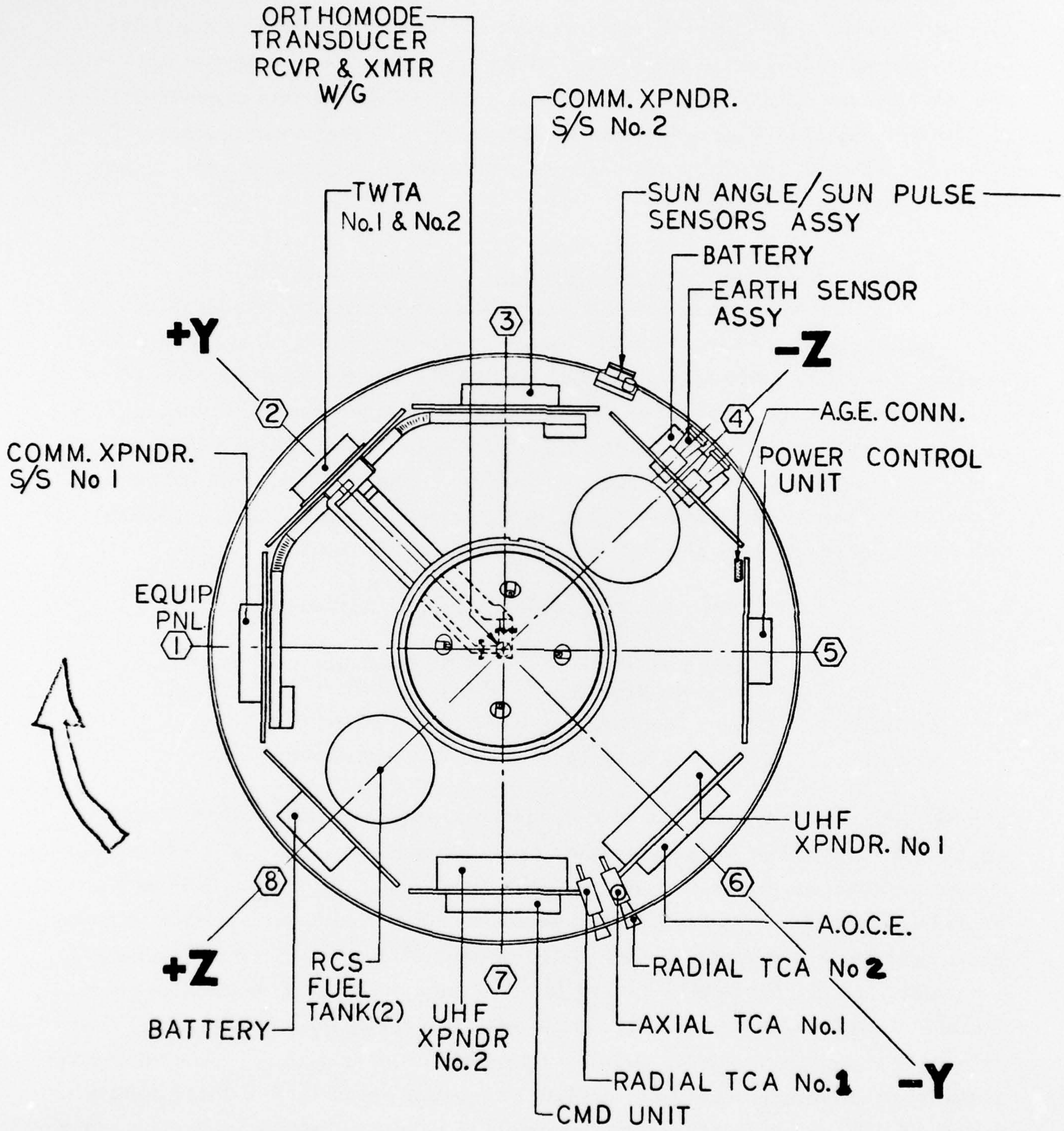


Figure 2

SKYNET I Satellite (Top View)

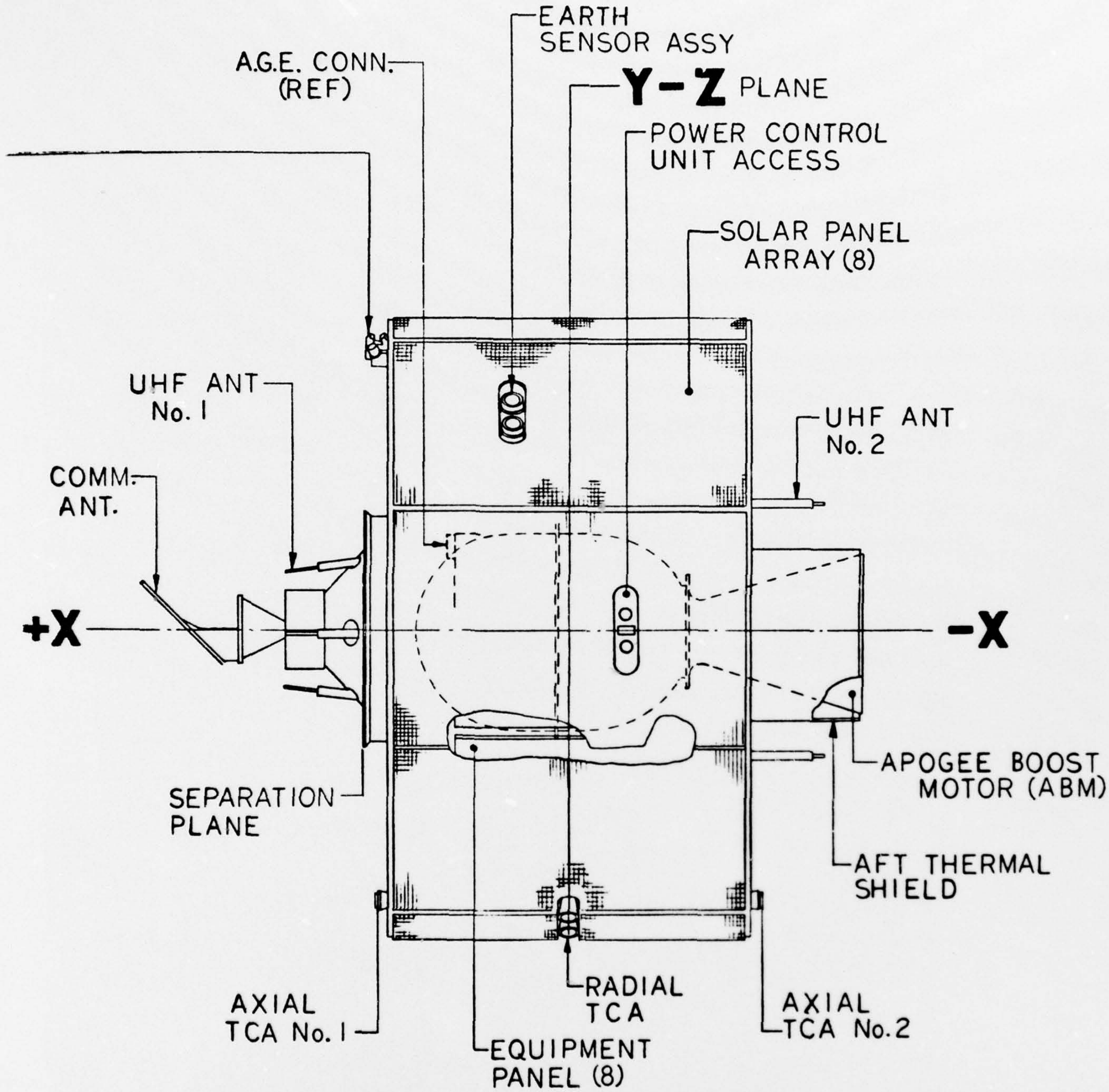


Figure 3

SKYNET I Satellite (Side View)

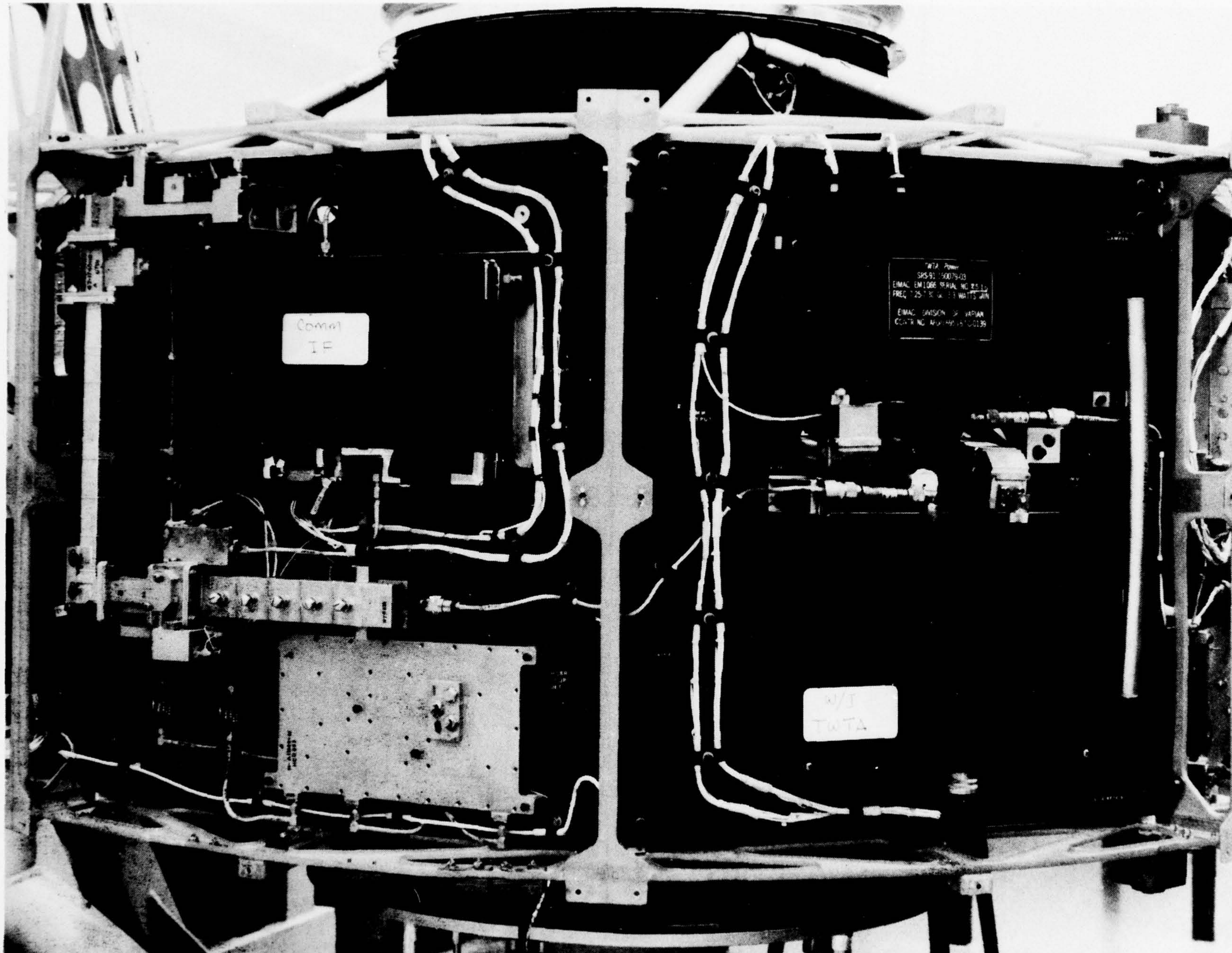


Figure 4 SKYNET I Panels 2 and 3

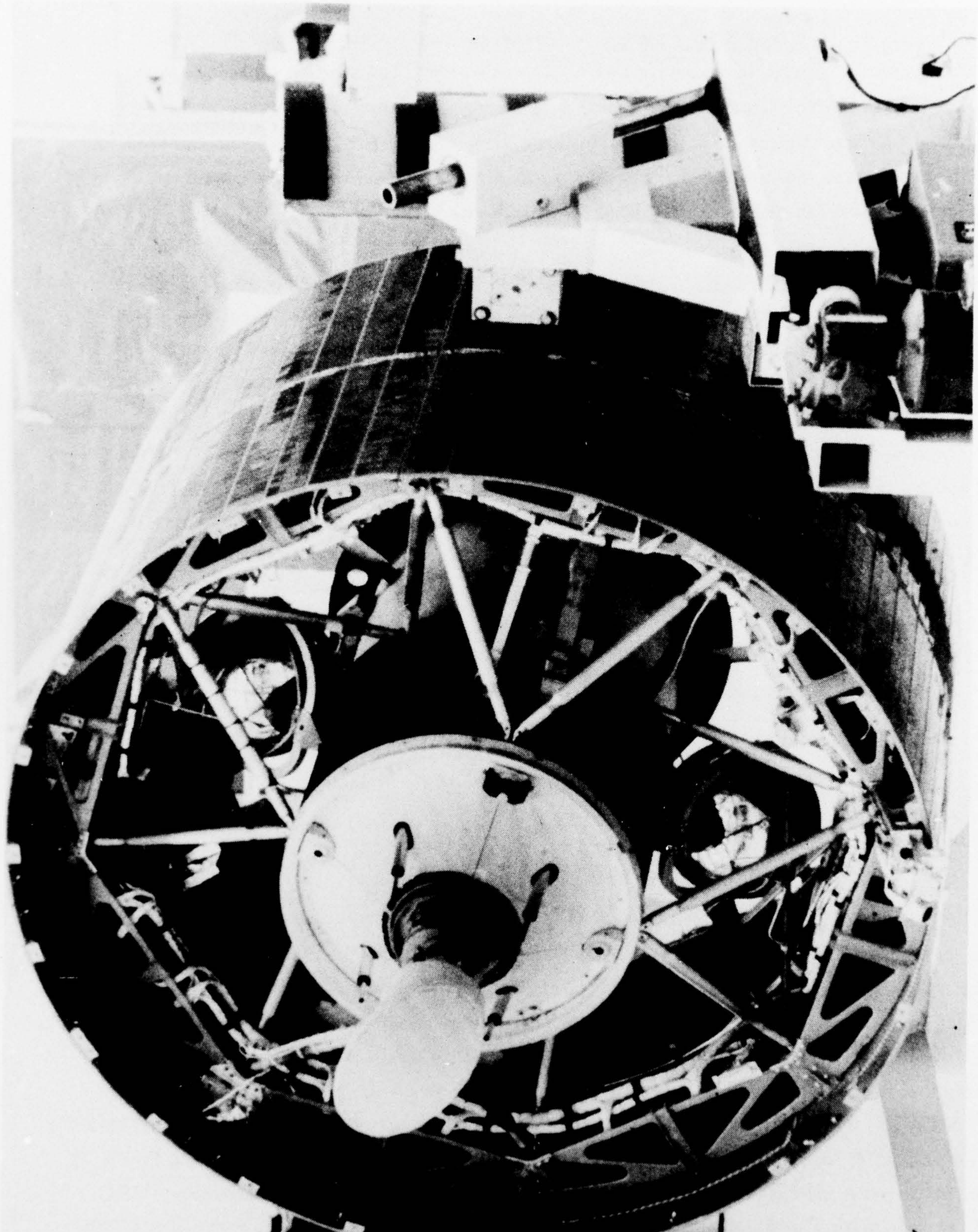


Figure 5. SKYNET I With Thermal Shield Removed

2.1.3 Electrical Power. The required electrical power (nominally 97 watts) was supplied by solar cells except during eclipse. During eclipse, two 16-cell Nickel Cadmuim batteries of 6 ampere/hour each were utilized for power. At synchronous orbit, eclipse occurs only during two short periods (~30 days) centered at the vernal and autummal equinoxes. The maximum eclipse period (at equinox) is about 70 minutes.

2.1.4 Station Keeping. Station keeping was effected by hydrazine reaction units controlled by an orientation control system utilizing sun, earth and sun angle sensors. These sensors provided the attitude and spin rate information and the reference pulses required for antenna pointing.

2.2 Related Satellite Programs. SKYNET I was a second generation satellite utilizing much of the technology from the Initial Defense Communication Satellite Program (IDCSP) which Ford Aerospace developed for USAF/SAMSO. SKYNET I had the following improvements over IDCSP:

Mechanically Despun Antenna

Attitude/Orbit Control

Batteries (Eclipse Operation)

Command Capability

An additional X-Band Communication Link

Higher Effective Radiated Power from Antenna

Earth Synchronous Orbit

Another version of this communication satellite, NATO II, was designed for the North Atlantic Treaty Organization. NATO II is essentially the same as SKYNET I, except for changes in operating frequencies and antenna patterns. Finally, SKYNET II was a follow-on replacement satellite which was also an upgrading of SKYNET I. The SKYNET II was a larger satellite, with more solar cells to power two higher-power Traveling-Wave Tube Amplifiers (TWTA's), 16 watts on SKYNET II vs. 3.5 watts on SKYNET I. Where SKYNET I and NATO II were fabricated and assembled by Ford Aerospace, the SKYNET II satellite was fabricated and assembled by the United Kingdom Company, GEC Marconi, with Ford Aerospace & Communications Corporation providing some of the hardware plus expertise.

2.3 <u>Chronology of SKYNET Type Satellites.</u> The four satellites mentioned above (IDCSP, SKYNET I, NATO II and SKYNET II) were designed, assembled and readied for launch in the 1965-75 decade. Table I, which was published in the February 1976 issue of Astronautics and Aeronautics (a publication of the American Institute of Astronautics and Aeronautics, AIAA) is a summary description of all of the military satellites of that period, up to and including the DSCS-II. As can be seen, all are spin-stabilized satellites, and most have a mechanically despun antenna (i.e., a "double spinner"). Figure 6 depicts in time sequence the various satellites for which Ford Aerospace was either prime contractor or a major contractor. As can be seen from Table I or Figure 6, SKYNET I is very representative of a "typical" spinning satellite.

2.4 <u>SKYNET/NATO History.</u> SKYNET IA was launched from Cape Canaveral in November, 1969, into an initial elliptical orbit of 276 by 36,732 km. The launch vehicle was a Long Tank Thrust-Augmented (LTTA) Thor-Delta. After two days, the apogee kick motor (AKM) was fired and the satellite was repositioned into an orbit of 34,710 by 36,695 km. SKYNET IA was then moved to its permanent station over the Indian Ocean. After an extensive integrated system check of satellite and Ground Stations, SKYNET IA became operational in mid 1970. SKYNET IA is presently non-active, the second TWTA having failed in November, 1972.

Failure of SKYNET IB's apogee kick motor (AKM) resulted in failure to achieve geostationary orbit and loss of this satellite to the United Kingdom's Defense Communications Network (August, 1970).

The following is a chronology of the launches of this SKYNET-type satellite:

SKYNET I (Flight 1) launched November 29, 1969

SKYNET I (Flight 2) launched August 19, 1970

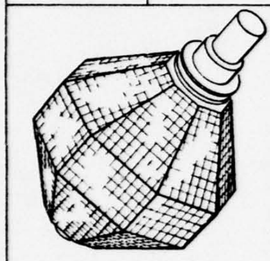
NATO-II (Flight 1) launched March 20, 1970

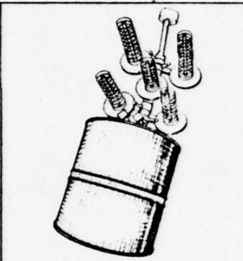
NATO-II (Flight 2) launched February 2, 1971

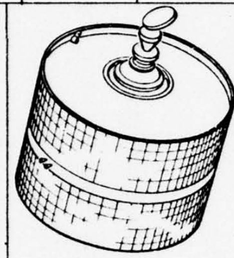
NATO II (Flight 2), which is still fully operational, is in its seventh year of operation.

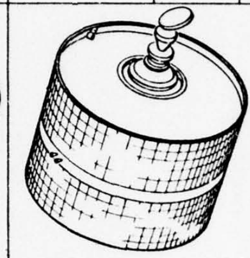
TABLE I MILITARY COMMUNICATION SATELLITES

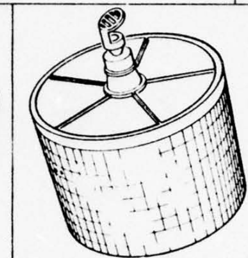
SATELLITE	PROGRAM OBJECTIVES[(1)]	DESIGNATION (OPS. NO.)	LAUNCH DATE (ALL AT ETR)	ORBIT	LAUNCH VEHICLE	APOGEE MOTOR	OPERATIONAL STATUS	COMMUNICATIONS SUBSYSTEM (ALL AT X-BAND)
IDCSP (Initial Defense Communication Satellite Program)	Establish a system of satellites in slightly sub-synchronous orbits providing full-time earth coverage 1.5-year design life (6-year timer)	9310 Series (7 Satellites)	6/16/66	18,000 nmi equatorial (~30° drift per day)	TITAN IIIC (A fifth series was lost due to launch vehicle failure)	None	All timed out or failed	One 20-MHz repeater Fixed biconical horn antenna 7 dbW ERP TWTA redundancy control unit (automatic)
		9320 Series (8 Satellites)	1/18/67				4 timed out or failed 4 operational as of 9/75	
		9330 Series (3 Satellites)	7/1/67				1 operational as of 9/75 2 failed	
		9340 Series (8 Satellites)	6/13/68				6 timed out 2 operational as of 9/75	
TACSAT (Tactical Communications Satellite)	Evaluate tactical communications by satellites Establish initial tactical communications capability 5-year design life	0757	2/9/69	Synchronous equatorial	TITAN IIIC	None	Despin control system failed 12/72	X-band 20W Three 20-W TWTAs (two active) Transmit and receive horns Transistor amplifiers UHF 16 solid state amplifiers (13 on) 5-bifilar helix antennas Tunnel diode preamplifier
SKYNET I	Establish an operational military communication satellite system for the U.K. (England to Hong Kong) 3-year design life	9351 (SKYNET IA)	11/21/69	Synchronous equatorial	THOR-DELTA M	Thiokol TE-M-521	Communication system failed 11/71	2 and 20-MHz bandwidth redundant transponders Two 3.5-W redundant TWTAs Mechanically despin antenna (earth coverage)
		9352 (SKYNET IB)	8/19/70				Satellite lost during burn of the apogee motor	
NATO II	Establish an operational communication satellite system for the NATO nations (IDCSP satellites were used for NATO I) 3-year design life	9361 (NATO IIA)	3/20/70	Synchronous equatorial	THOR-DELTA M	Thiokol TE-M-521	Communication system failed 6/72	Antenna modified for NATO coverage only Equal RF power split between 2 and 20 MHz channels
		9362 (NATO IIB)	2/2/71				Satellite in operation as of 9/75	
SKYNET II	Replacement and upgrading of the SKYNET I system 5-year design life	9353 (SKYNET IIA)	1/18/74	Synchronous equatorial	DELTA 2313	Thiokol TE-M-604	Satellite lost due to failure in the launch vehicle second stage	2 and 20-MHz bandwidth redundant transponders Two 16-W redundant TWTAs Mechanically despun antenna (earth coverage)
		9354 (SKYNET IIB)	11/22/74				Satellite in operation as of 9/75	
DSCS II (Defense Satellite Communication System)	Replacement and upgrading of the IDCSP (DSCS I) system 5-year design life	9431 9432	11/2/71	Synchronous equatorial	TITAN IIIC	None	Despin control system failure (9431 in 9/72 and 9432 in 9/73)	Four channels Straight-through earth coverage (EC) Straight-through narrow beam (NB) Receive NB; transmit EC Receive EC; transmit NB TWTs Two EC and two NB antennas on despun platform
		9433 9434	12/13/73				Both satellites operational as of 9/75	
		9435 9436	5/20/75				Satellites lost due to failure of the launch vehicle	

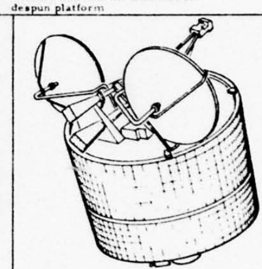

IDCSP


TACSAT


SKYNET I


NATO II


SKYNET II


DSCS II

(1) The satellites operate with many types of data and terminals - the number of circuits is primarily dependent on ground antenna size and the level of interference.

TABLE I MILITARY COMMUNICATION SATELLITES (Continued)

SATELLITE	GENERAL DESCRIPTION	DRY MASS (kg)	ATTITUDE AND ORBIT CONTROL	ELECTRICAL POWER	TELEMETRY AND COMMAND		PROCUREMENT AGENCIES AND PRIME CONTRACTORS
IDCSP (Initial Defense Communication Satellite Program)	Modified octahedron Spin stabilized Fixed antenna 86 cm Diameter 81 cm High	14 Communications 4 TTC(1) 12 Power 10 Structure 6 Misc 46 On Orbit	150 rpm Spin rate (N_2 spinup system)	40 W BOL(2) 8,000 2 × 2 cm Solar cells No batteries	UHF 8-bit data word 64-word main frame 256 bits/sec No redundancy Antenna	No command system (end-of-life timer)	Satellite procurement-USAF Satellite contractor- Philco-Ford Launch vehicle procurement- USAF Launch vehicle contractor- Martin Marietta
TACSAT (Tactical Communications Satellite)	Cylinder Spin stabilized Despun antenna and equipment platform 274 cm Diameter 762 cm High	86 Communications 54 TTC(1) 23 Reaction Control 55 Spin 132 Power 300 Structure(3) 650 On Orbit	54 rpm Spin rate 2 Earth sensors 1 Sun sensor 66 kg H_2O_2 Propellant 2 Axial thrusters 2 Radial thrusters Passive nutation damper	980 W BOL(2) 60,000 2 × 2 cm Solar cells 3 NiCd Batteries 6 amp hr each	S-Band 8-bit data word 128-word main frame 32 and 64 words/sec Redundant transmitter Antenna	20-bit command 196-command vocabulary 1000 bits/sec Redundant receivers/decryptors Redundant processors	Satellite procurement-USAF Satellite contractor-Hughes Launch vehicle procurement- USAF Launch vehicle contractor- Martin Marietta
SKYNET I	Cylinder Spin stabilized Mechanically despun antenna 137 cm Diameter 157 cm High	23 Communications 14 TTC(1) 16 Reaction Control 6 Attitude/Orbit Control 34 Power 23 Structure(3) 116 On Orbit	90 rpm Spin rate 2 Earth sensors 2 Sun sensors Dual sun angle sensor 11.4 kg N_2H_4 Propellant 2 Axial thrusters 2 Radial thrusters Passive nutation damper	113 W BOL(2) 7200 2 × 2 cm Solar cells 2 NiCd Batteries 6 amp hr each	UHF 7-bit data word 64-word main frame 32 words/sec Redundant transmitters Redundant antennas	25-bit command 64-command vocabulary 200 bits/sec Redundant receivers/processors	Satellite procurement-USAF for U.K. MOD(4) Satellite contractor- Philco-Ford Launch vehicle procurement- NASA through USAF Launch vehicle contractor- McDonnell-Douglas
NATO II	(same as SKYNET I)	same as SKYNET I)	(same as SKYNET I)	(same as SKYNET I)	(same as SKYNET I)		Satellite procurement- USAF for NATO Satellite contractor- Philco-Ford Launch vehicle procurement- NASA through USAF Launch vehicle contractor- McDonnell-Douglas
SKYNET II	Cylinder Spin stabilized Mechanically despun antenna 191 cm Diameter 209 cm High	31 Communications 25 TTC(1) 6 Reaction Control 7 Attitude/Orbit Control 69 Power 46 Structure(3) 25 Misc 209 On Orbit	90 rpm Spin rate 4 Earth sensors Dual sun angle sensor 22.7 kg N_2H_4 Propellant 2 Axial thrusters 2 Radial thrusters Passive nutation damper	260 W BOL(2) 16,000 2 × 2 cm Solar cells 2 NiCd Batteries 12 amp hr each	S-Band 7-bit data word 64-word main frame 32 words/sec Redundant encryptors/transmitters 54-Element antenna	20-bit command 64-command vocabulary 1000 bits/sec Redundant receivers/decryptors/processors	Satellite procurement- U.K. MOD(4) Satellite contractor-Marconi Space and Defence Systems, Ltd. Launch vehicle procurement- NASA through USAF Launch vehicle contractor- McDonnell-Douglas
DSCS II (Defense Satellite Communication System)	Cylinder Spin stabilized EC&NB despun antennas and equipment platform 274 cm Diameter 396 cm High	106 Communications 36 TTC(1) 69 Reaction Control 55 Attitude/Orbit Control 142 Power 135 Structure 17 Thermal 560 On Orbit	60 rpm Spin rate 2 Earth sensors 53.5 kg N_2H_2 Propellant 2 Axial thrusters 2 Radial thrusters Passive nutation damper	535 W BOL(2) 33,000 2 × 2 cm Solar cells 3 NiCd Batteries 12 amp hr each	S-Band 8-bit data word 32-word main frame 32 words/sec Redundant Bicone antenna	20-bit command word 288-command vocabulary 1000 bits/sec Redundant	Satellite procurement-USAF Satellite contractor-TRW Launch vehicle procurement- USAF Launch vehicle contractor- Martin Marietta

(1) TT&C - Tracking, telemetry, and command subsystem
(2) BOL - Beginning of life
(3) Includes thermal control
(4) MOD - Ministry of Defence

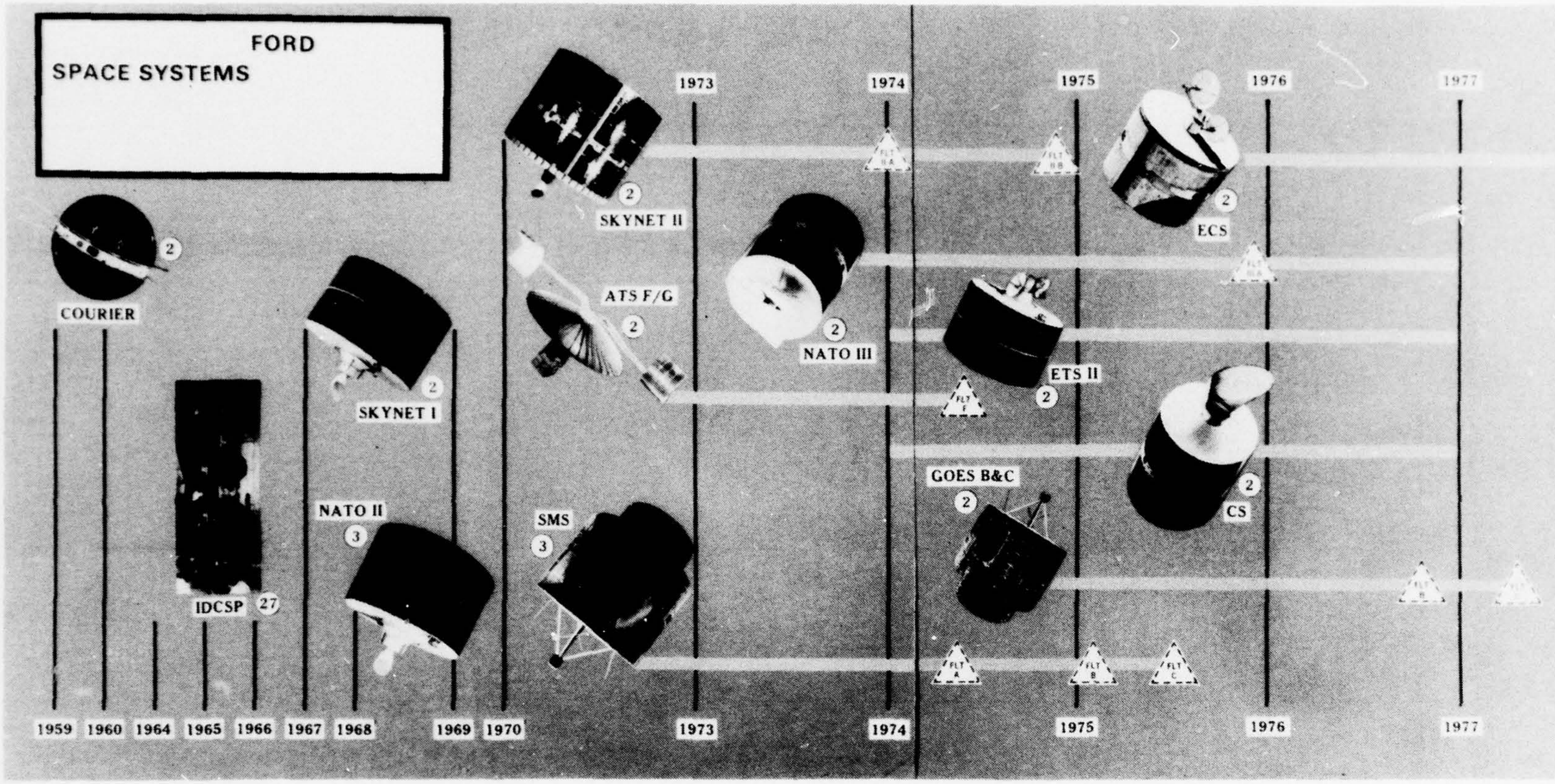


Figure 6. Spectrum of Ford Aerospace Satellites

3.0 THE SKYNET I QUALIFICATION MODEL

Before a satellite is commited to manufacture, the design is established and proved based upon the results obtained from both extensive analyses and from tests conducted with early mechanical, thermal, and occasionally engineering, models of the satellite. This piece-meal proven design is released for manufacture, with one unit (usually the first production item) designated as the qualification model (qual model). The qual model is required to fully meet all functional performance requirements, and is subjected to a sequence of environments which are somewhat more stringent than the extremes anticipated either during handling or storage, shipping, launch, transorbital, or on-orbit conditions.

Once the qual model has passed all of the qualification tests, the flight units are assembled in this proven configuration, tested to a reduced level, and launched. The residual qual model can be used to:

a. Serve as a testbed to investigate flight model malfunctions.

b. Become a later flight model, after refurbishment.

The SKYNET I qualification unit was never refurbished for flight. Also, during the later phases of the SKYNET I and NATO II programs, certain components were removed for other uses. After completion of these programs, WDL placed the qual model on display at its Palo Alto facility. During 1974, when it became apparent that SGEMP was becoming important for satellite survivability, WDL offered the SKYNET I qualification model satellite to DNA as a test specimen, to be used to better define and understand SGEMP. This led directly to the initiation of the SKYNET SGEMP Program.

3.1 History of the SKYNET I Qual Model. The fabrication of the Qual Model of SKYNET I was begun in February, 1968, with assembly beginning in August, 1968. Final testing was completed in March, 1969. After the follow-on Flight units had achieved orbit and the qual model had little further usage on the program, it was placed on exhibition at the WDL facility in Palo Alto, California in 1971.

3.2 <u>Status of SKYNET I Qual Model Available for SGEMP Testing.</u>

The Quality Assurance Inspection Records list the following Qual Model items as missing (i.e., removed), or damaged at the time when the unit was selected as the SGEMP test specimen:

- o Comm Antenna (Reflector) Damaged
- o Earth Sensors (2 each) Missing
- o Sun Guard Sensors (2 each) Missing
- o A few Cracked Solar Cells (Covers) as Charted
- o Thrust-Control Assembly (TCA) Valve Drivers Missing (4 each)
- o Dummy TCA's in place of Flight Units
- o Corrosion and Cracked Insulation in 4 spots
- o Solar Panel Web Broken (2 places)
- o One Non-Flight RF Switch Installed
- o Motor Drive Assembly (MDA) Exposed to Environments W/O Purge
- o Minor Cosmetic and Wiring Harness Discrepancies
- o Batteries (2 each) in Refrigerated Storage (not used)
- o The AKM was not in place, but it was to be replaced, on the SGEMP Program, by a spool which was to hold the SKYNET I in an upright position for either shipping, storage or test.

4.0 MODIFICATIONS MADE TO THE SKYNET I QUAL MODEL SATELLITE FOR THE SGEMP PROGRAM

To place the satellite in the SGEMP test configuration, criteria were established, jointly with IRT and HDL, as to what units were to be tested in flight configuration, which units were to be dummies, which boxes were to have test (simple) circuitry in or on the sub unit, and which items could be omitted. As soon as this was determined, the qual model was removed from display, partially disassembled to affect the required changes, reassembled to the test configuration and shipped to the SGEMP test site.

Table II lists both the original and dummy boxes and their location on the SKYNET I SGEMP Satellite. Figure 7 shows, as a group, most of the qual model electronic boxes replaced by dummies. Figure 7 shows a group of the "real" satellite components removed from the satellite. Illustrative of the dummy units used to replace some components is the TWTA shown in Figure 8, which replaced the original TWTA which can be seen at the lower left corner of Figure 7. Similarly, Figure 9 shows the dummy Ultra-High Frequency (UHF) Diplexer which replaced the Diplexer in the upper center of Figure 7.

All electronic boxes (whether original or dummy) were grounded to the equipment platform using the same scheme as the Qual Model Satellite. Except for the missing earth sensors, sun guard sensors, TCA valves, batteries and AKM, all other components were present as either real or dummy units.

4.1 Modification of Solar Panels. The eight solar panels from the Qual Model SKYNET I were modified by placing 9 inserts, which provided an electrical connection to the panel core, on each solar panel. Figure 10 shows four solar panels, showing the inward-facing side of the solar panels; in each panel, the 9 white "dots" are the insert test points.

4.2 Cable Harnessing. The various electrical and electronic components and/or subsystems of a satellite are interconnected by myriad interconnecting wires and cables. These wires/cables are integrated into one of two harness assemblies: the main harness (see Figure 11) and the power harness (see Figure 12). The harness configurations shown resulted from a system tradeoff which took into consideration:

TABLE II

Summary of Types, Locations of Real and Dummy Components on Test Satellite

Item	Equipment Panel No.	Inboard (I) or Outboard (O)	Flight or Dummy
Local Oscillator 1	3	I	Dummy
Local Oscillator 2	1	I	Dummy
Hybrid Coupler 1	1	O	Flight
Hybrid Coupler 2	3	O	Flight
Comm. I.F. 1	1	O	Flight
Comm. I.F. 2	3	O	Dummy
TWTA 1	2	O	Dummy
TWTA 2	2	O	Flight
UHF Diplexer	7	I	Dummy
Telemetry Unit	3	I	Dummy
Control & Timing Unit	7	O	Flight
Command Unit	7	O	Dummy
Attitude & Orbital Control Electronics (AOCE)	6	O	Dummy
Power Control Unit (PCU)	5	O	Dummy
Battery 1	4	O	Dummy
Battery 2	8	O	Dummy
Comm. DC-DC Conv. 1	8	I	Flight
Comm. DC-DC Conv. 2	8	I	Dummy

Figure 7. SKYNET I Electronic Components Removed from Satellite Prior to Testing

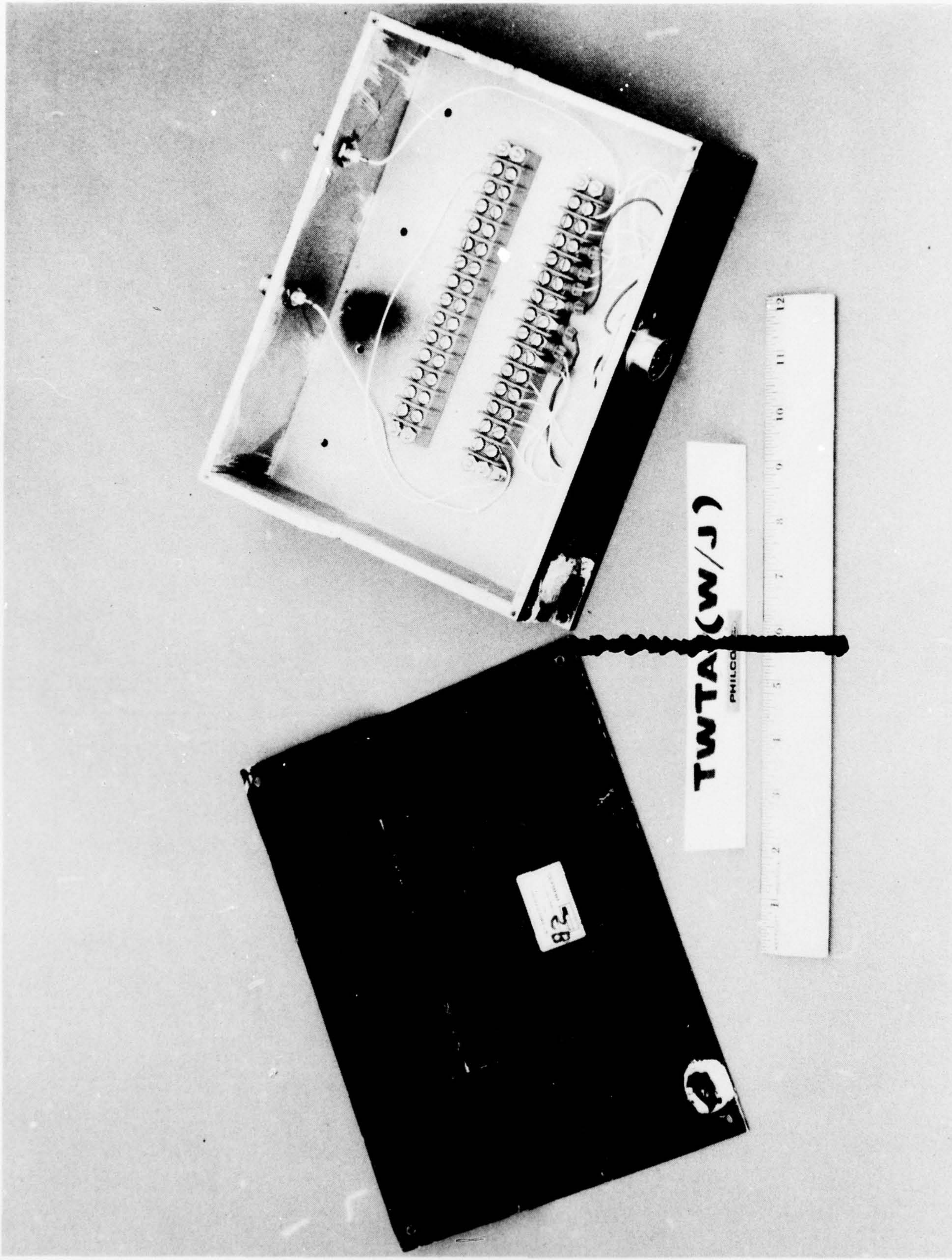


Figure 8. Dummy Watkins Johnson TWTA

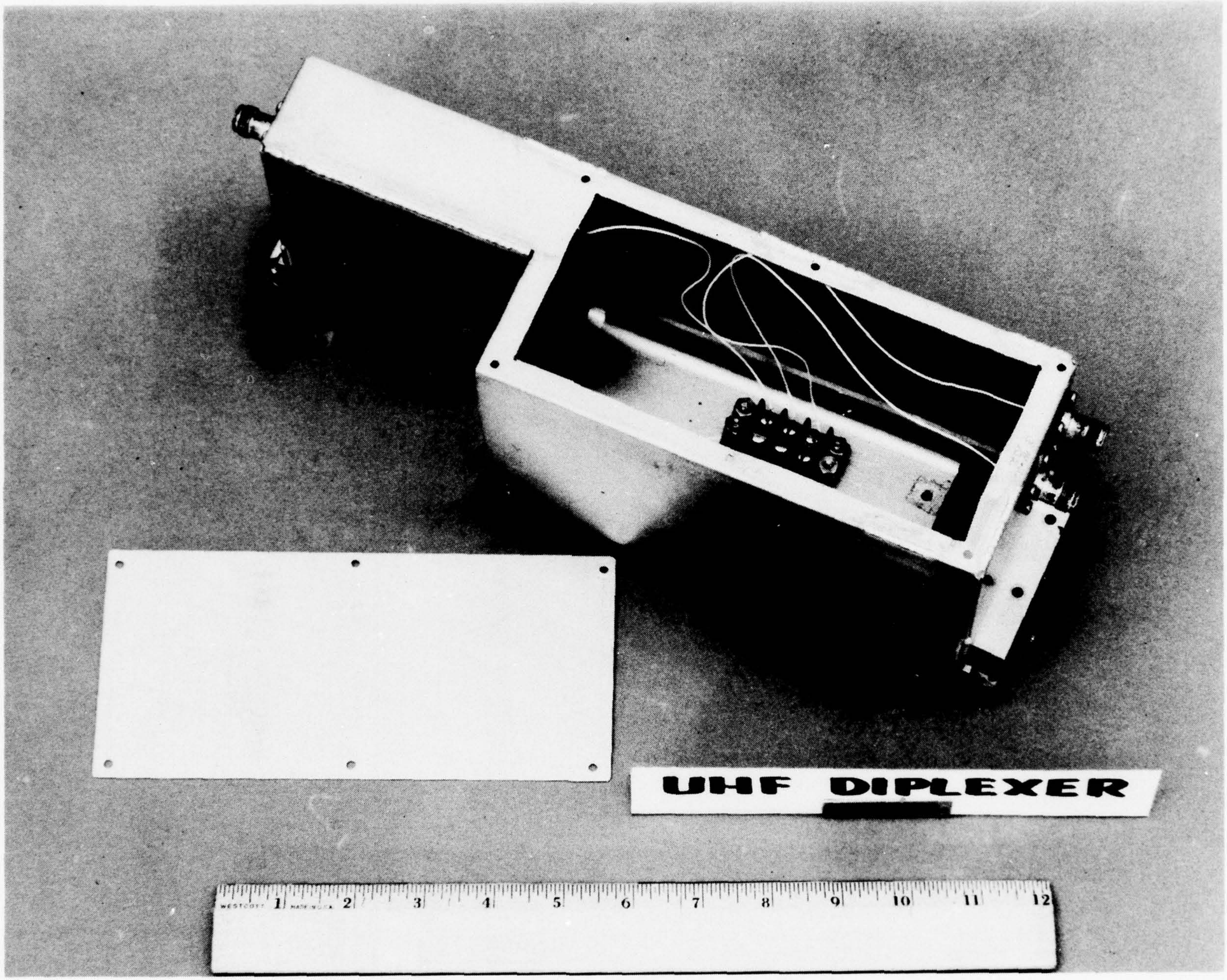


Figure 9. Dummy UHF Diplexer

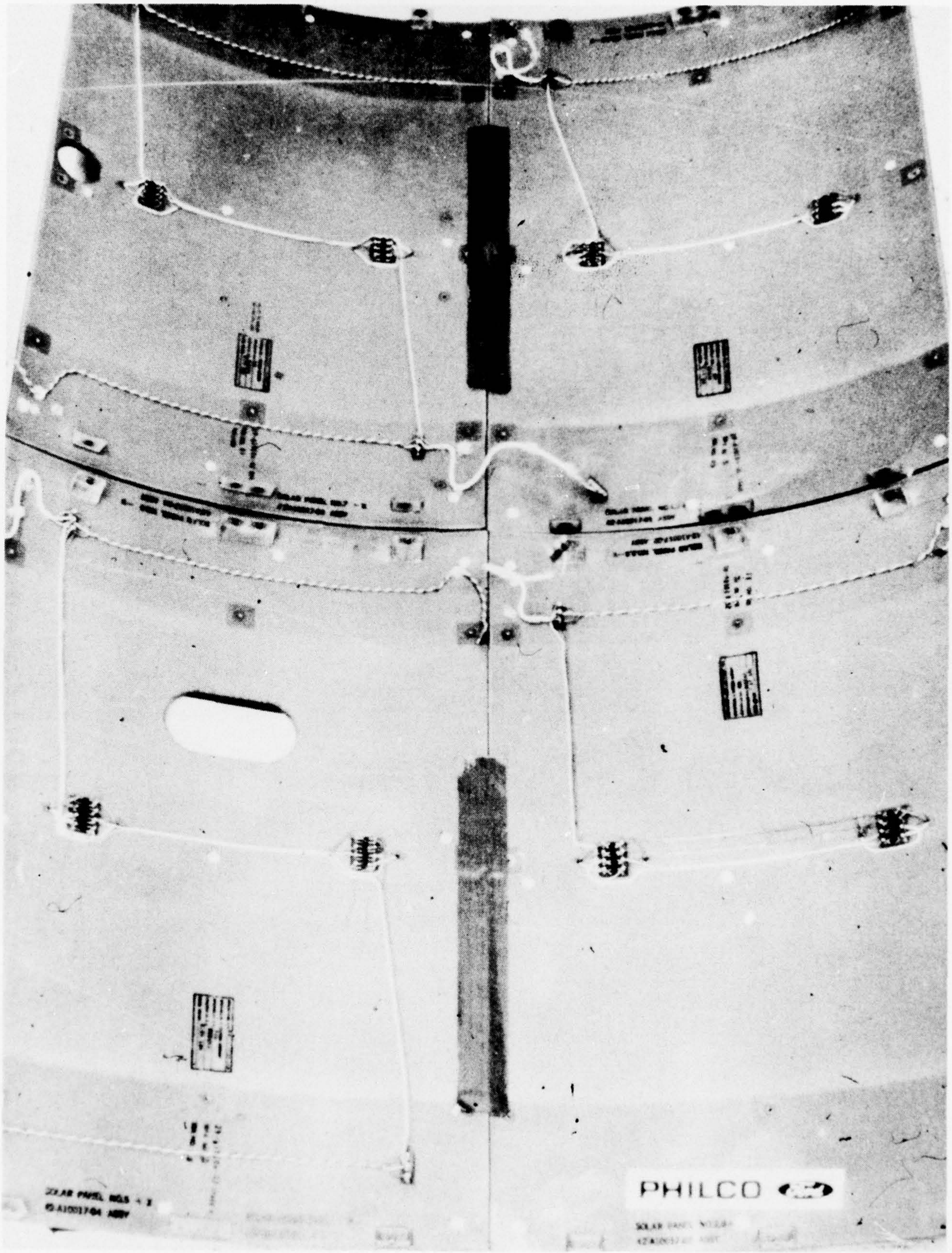


Figure 10. Solar Panel Array

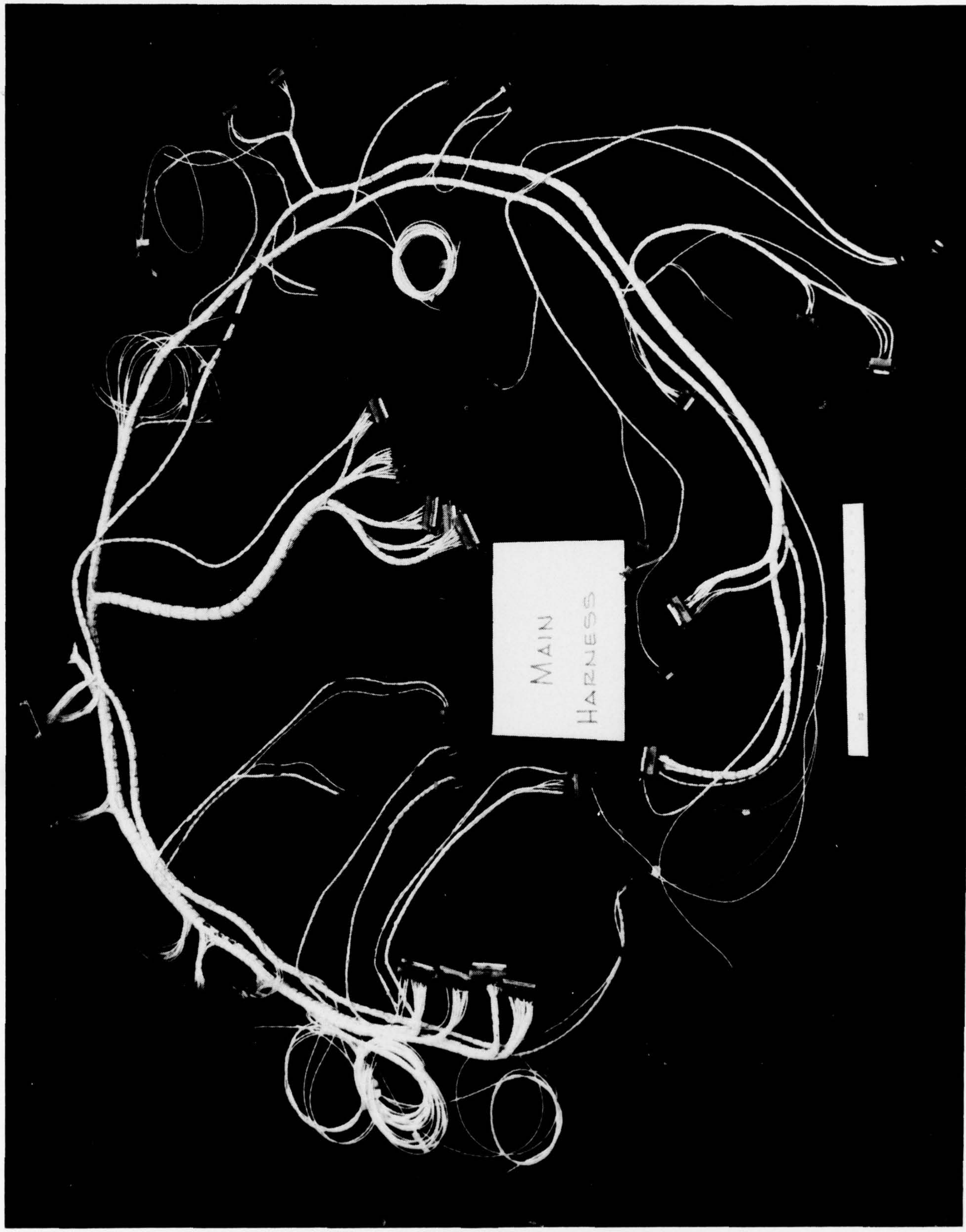


Figure 11. Main Harness

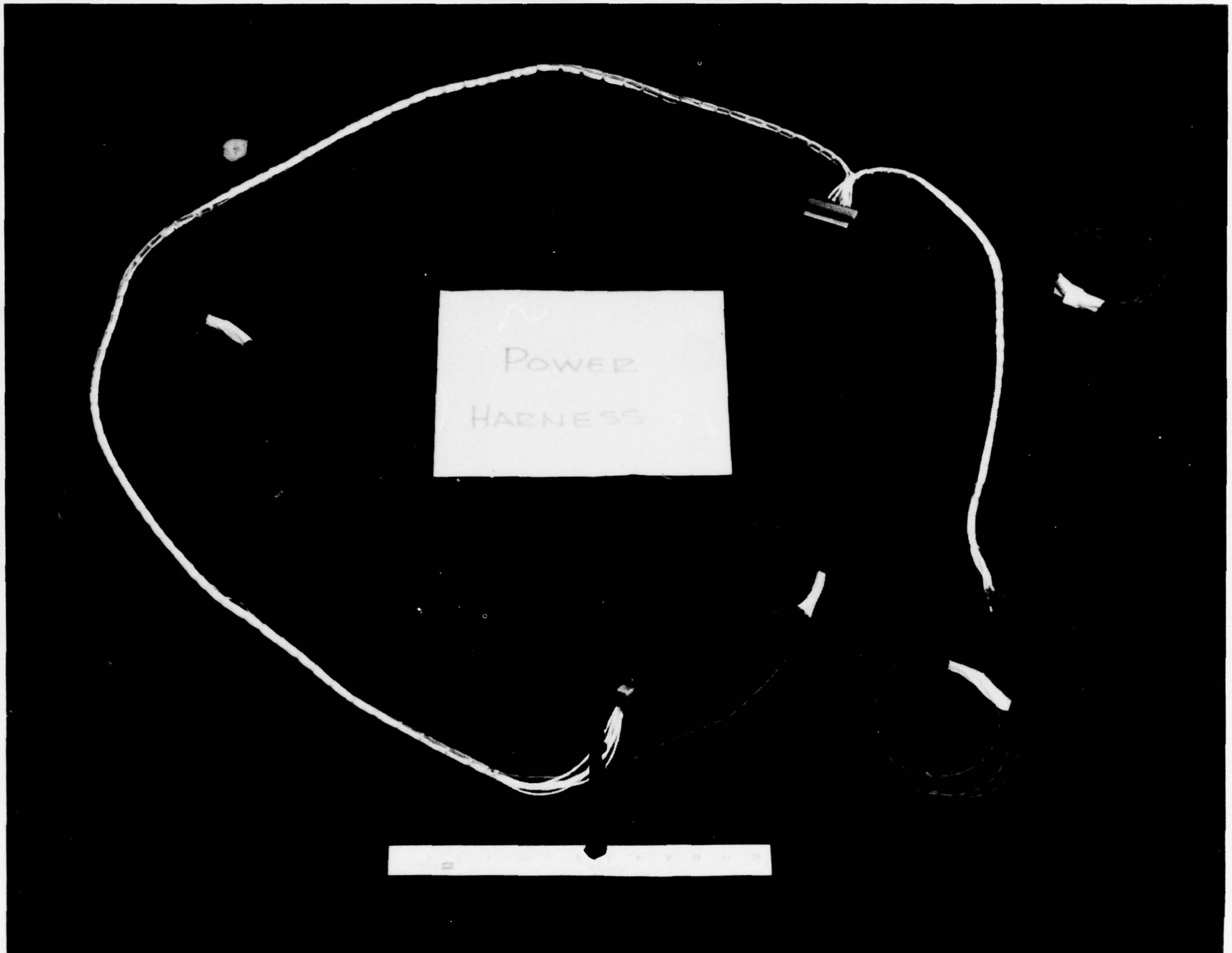


Figure 12. Power Harness

- o The box designers interest in minimizing cable length and utilization of maximum shielding.

- o The structural designers' satellite configuration, allowable routings, and available mechanical tie points.

- o The mechanical integration engineer, who is responsible for positioning boxes and cables (which have mass/inertia properties) both to properly balance the satellite and to yield the proper moment-of-inertia ratio, with a minimum of counter balancing weights.

- o The electrical integration engineer, who is concerned with minimizing or eliminating adverse Electromagnetic Interference (EMI) problems.

These harness extend longitudinally, radially and azimuthally within the satellite volume bounded by the thermal blankets (on the ends) and the solar panels. A look at Figures 4 and 5 reveals how such a harness is attached to the equipment platforms, aluminum struts, and other structural items. The actual flight harness was in place for these tests. When a given component (e.g., the earth sensor) was missing, the harness connector to that component was electrically grounded and physically taped to the mounting bracket.

It should be noted that the Skynet I satellite harness employs selective shielding of those wires that specifically required it. This is not typical of most later satellites, which tend to utilize over-all tape-wrap shielding of cable bundles, as such tape provides overall shielding at minimum weight penalty.

4.3 Dummy Boxes. The techniques used for dummy box assembly were:

4.3.1 Connectors/Terminations.

a. Power Connectors - The connector shield grounds were commoned together and secured to the chassis ground point within each box.

b. Signal Connectors with less than 25 pins – The individual leads were run to a terminal board from each connector pin within the box.

c. Signal Connector with 25 or more pins – All pins, except the shield grounds, were shorted and a single lead was run to a terminal board.

d. RF Connectors – The individual leads from each connector center conductor were run to a terminal board (the same terminal board as used for the power connector within the same box).

4.3.2 Access. For boxes with internal terminal strips, provisions were made for easy removal of all or part of the box cover for easy access to these strips.

4.3.3 Ground Strapping. Ground straps were secured to all boxes, real or dummy.

4.3.4 Ground Pins. The grounding of all boxes, original or dummy, followed the scheme used for the Qual Model SKYNET I.

4.3.5 Motor Drive Assembly (MDA). The Flight MDA had long ago been replaced with a dummy MDA (see Figure 13 and 14). This dummy MDA was reworked, however, to:

a. Provide 2 each BNC coaxial connectors on the lower body-fixed portion of the MDA;

b. Provide 2 each electrical ground straps between the comm antenna and the MDA (requested by IRT, since the comm antenna is otherwise isolated from the MDA by a dielectric material mounting plate);

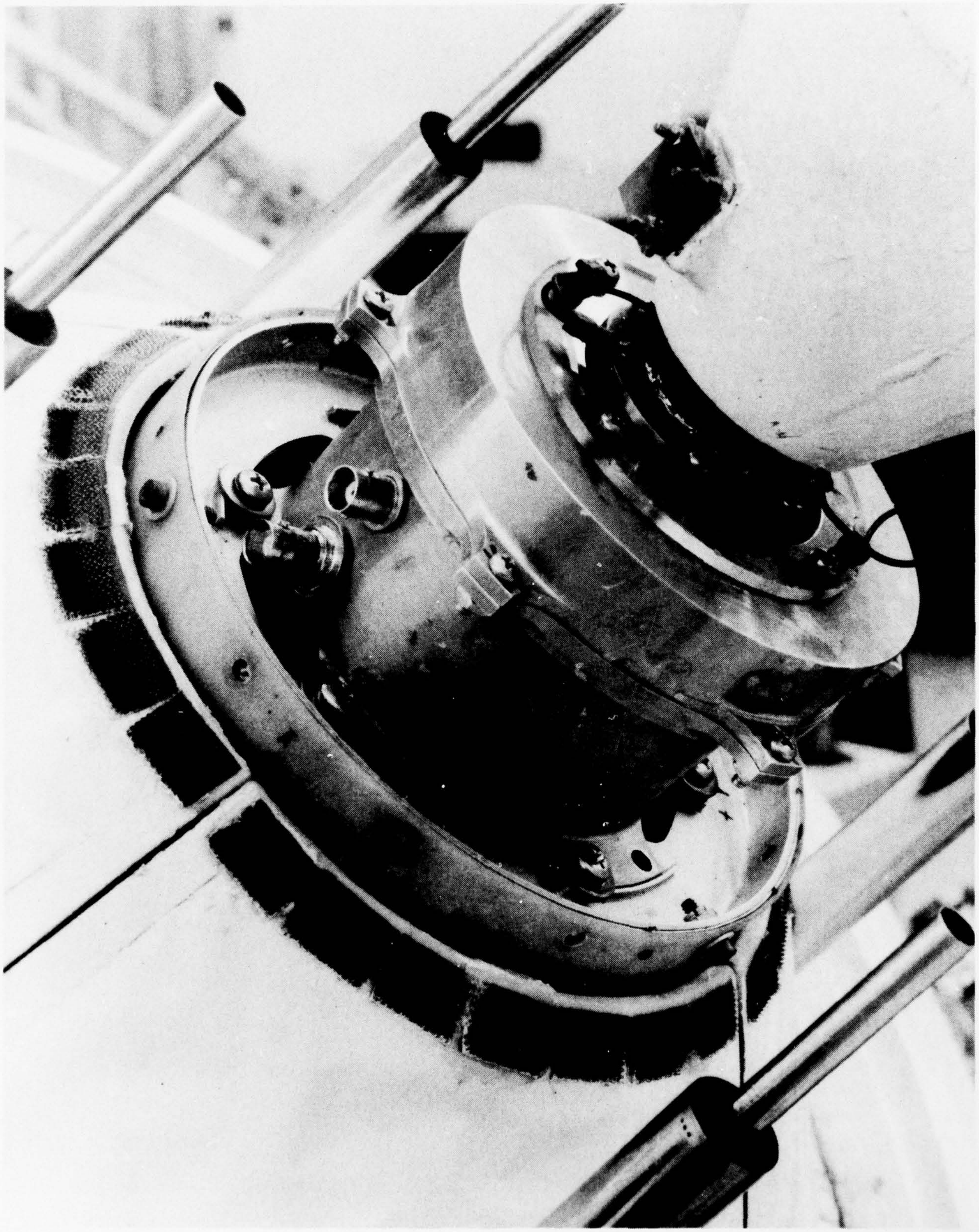


Figure 13. Dummy MDA

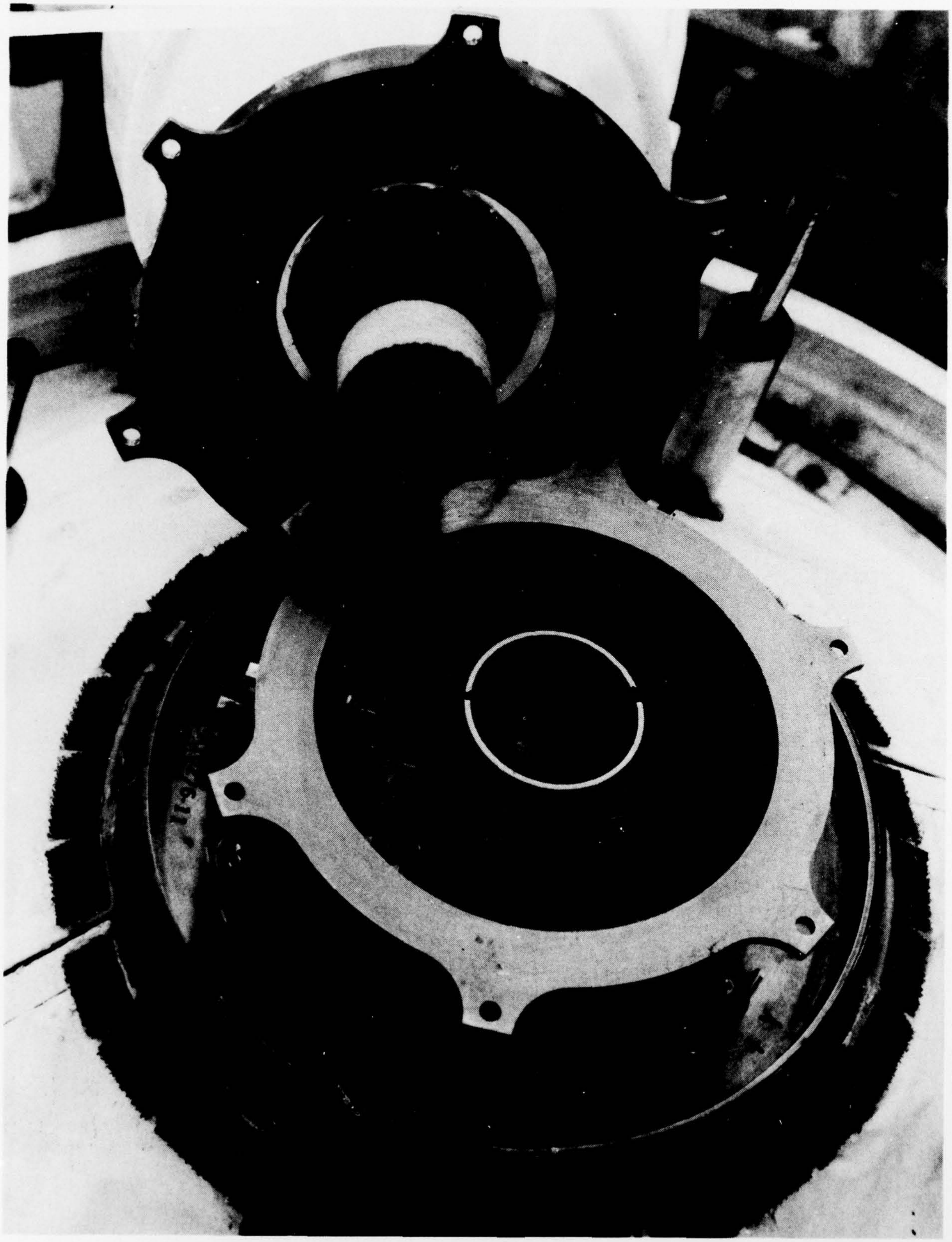


Figure 14. Details of Dummy MDA

c. Simulate the antenna waveguide rotary joint by 2 concentric tubes isolated by a layer of dielectric material on the outer surface of the inner tube (see Figure 14);

d. Add a small terminal strip, for ease of testing, on the inner surface of the lower portion of the MDA (see Figure 14).

5.0 SKYNET TEST FIXTURES

During meetings at WDL in October and December, 1974, HDL and IRT iteratively defined their satellite positioning/test requirements for the C-I tests and WDL designed the necessary fixturing to meet these requirements. Basically, IRT wanted the satellite positioned 2-3 satellite diameters from any surfaces, with this being accomplished without the use of metal. Also, the fixturing had to be compatible with the following conditions: (a) testing was to be done at a remote facility, which completely lacked any semblance of a clean or controlled environment; (b) several test sequences (approximately 2-week duration each) were to be carried out, with typically 2-3 months between sequences; (c) during test sequences, HDL engineers would require frequent access to the satellite, both exterior and interior, to position the pulsers and various sensor devices. In support, WDL generated a "SKYNET/SGEMP Test Configuration Assembly/Disassembly Procedure", WDL-SB-247152, which details all the steps required to install and remove the satellite from its shipping container, prepare it for tests, and to disassemble/assemble it for changing test configurations. Paragraphs 5.1 through 5.3 describe the fixturing designed and used for the current injection tests at Fort Belvoir.

Similar planning sessions for the EWR tests were held with MRC in April-June 1977. Paragraph 5.4 describes the fixtures for the testing at PI.

5.1 Shipping/Storage Container. WDL designed a special, wooden shipping case for shipping the SKYNET across the country to and from the FREME facility in Virginia. Figure 15 shows the SKYNET in this container. Inasmuch as the container would also serve as a storage container for periods of several months between test sequences, WDL included both desiccants to reduce the humidity within the box and a plug-type humidity indicator in the box side wall to allow the determination of the internal humidity without opening the container.

5.2 Test Stand. To place the SKYNET Satellite in the test configuration, the metal storage spool (see Figure 16), was removed and replaced by a plexiglass spool (see Figure 17). This satellite/spool configuration was in turn lowered on and fastened to a 5-foot high wooden stand (see Figure 18), which positioned the center of the satellite about 8 feet above the test area floor, or about the center of the 16-foot high test enclosure.

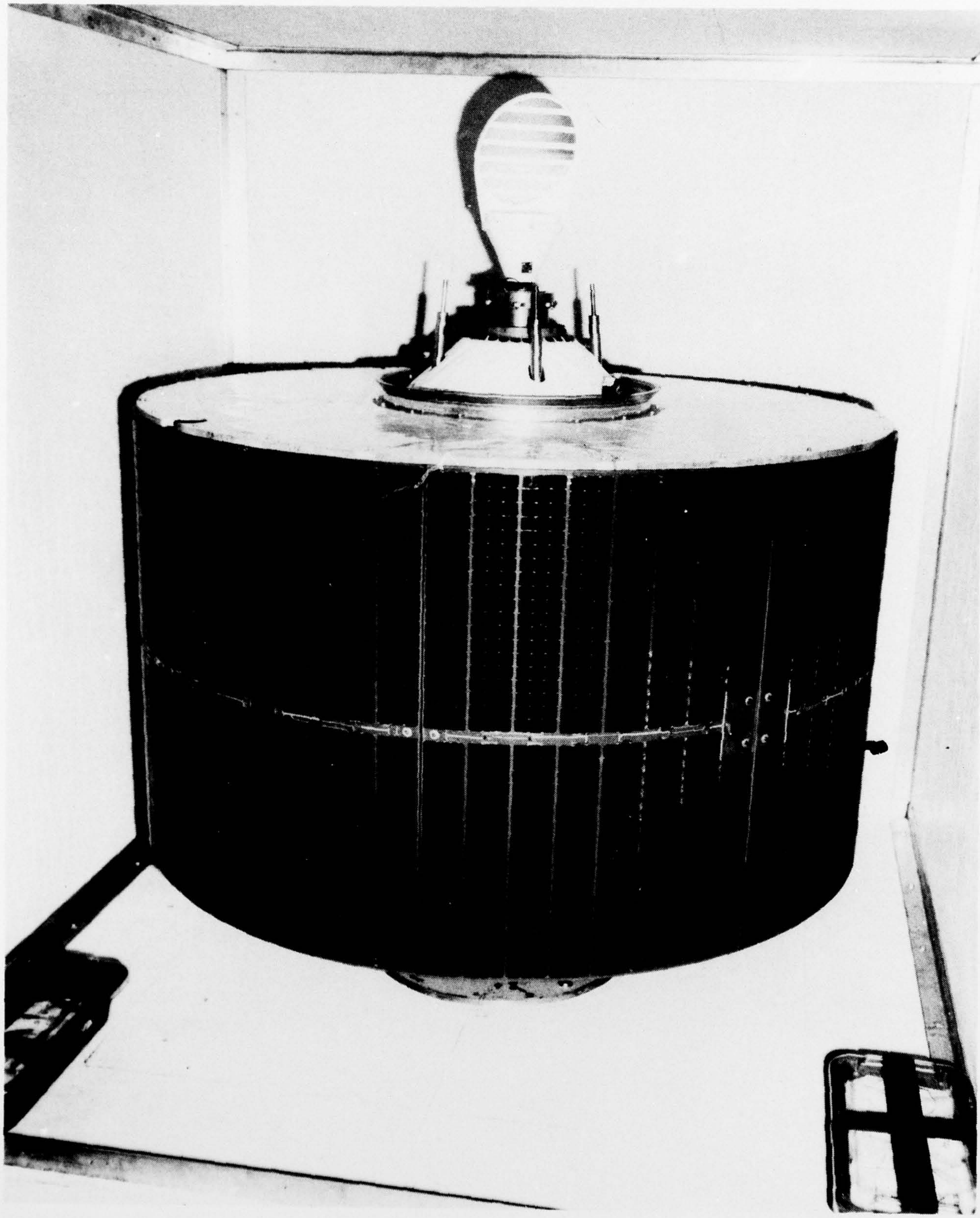


Figure 15. SKYNET SGEMP Satellite in Shipping/Storage Container

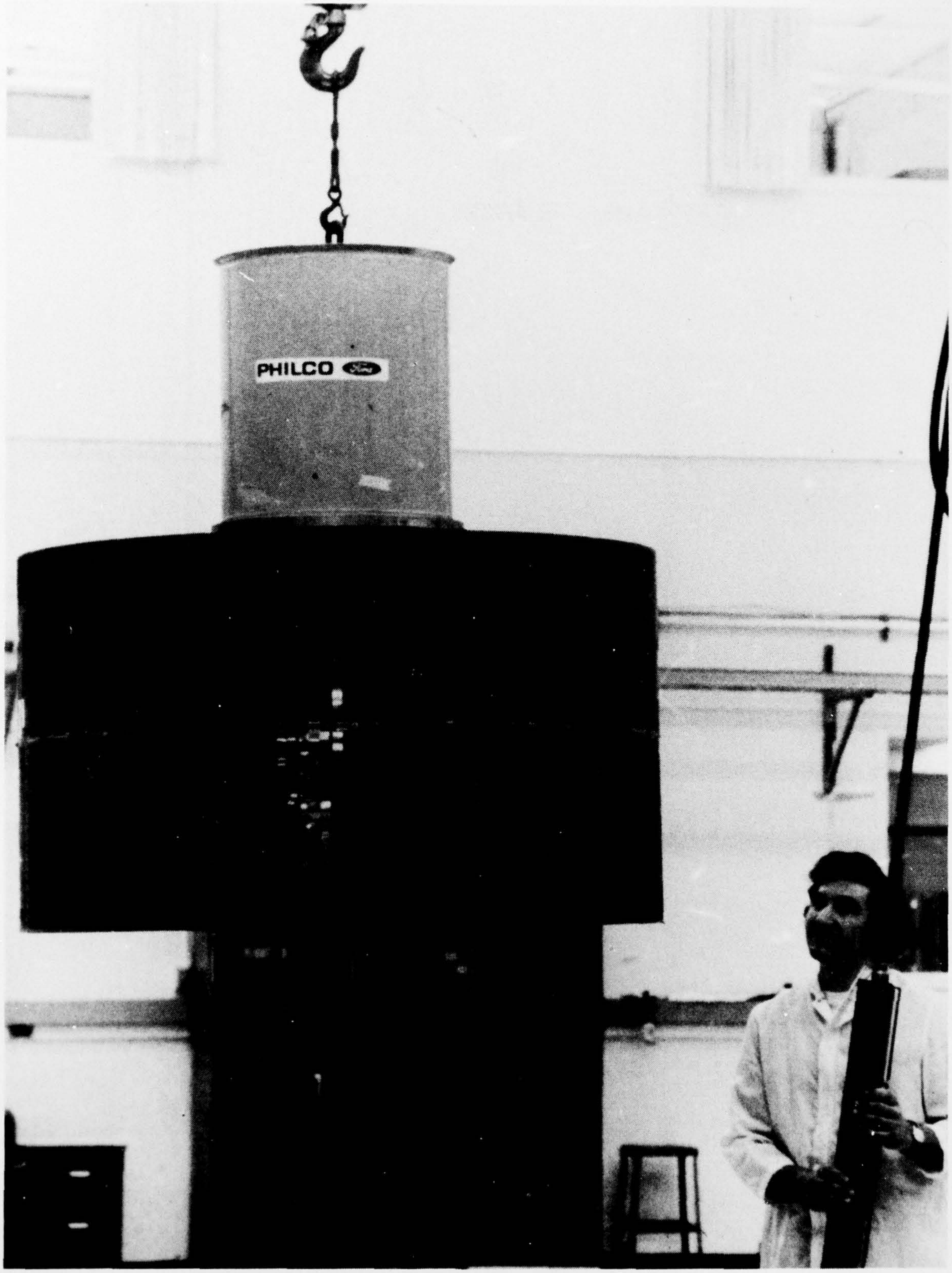


Figure 16. SKYNET Satellite with Normal Metallic Support Spool

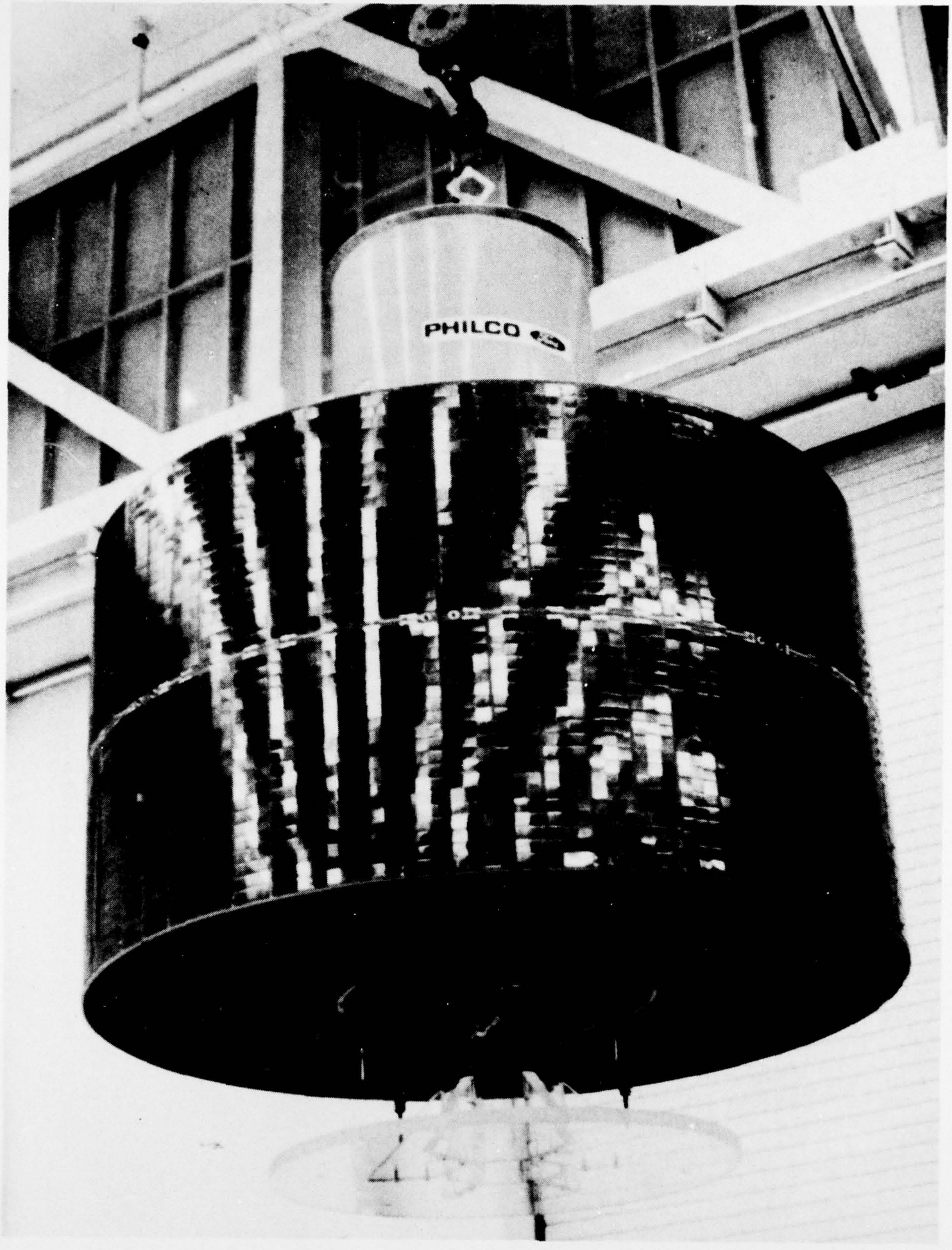


Figure 17. SKYNET Satellite With Special Plexiglass Support Spool

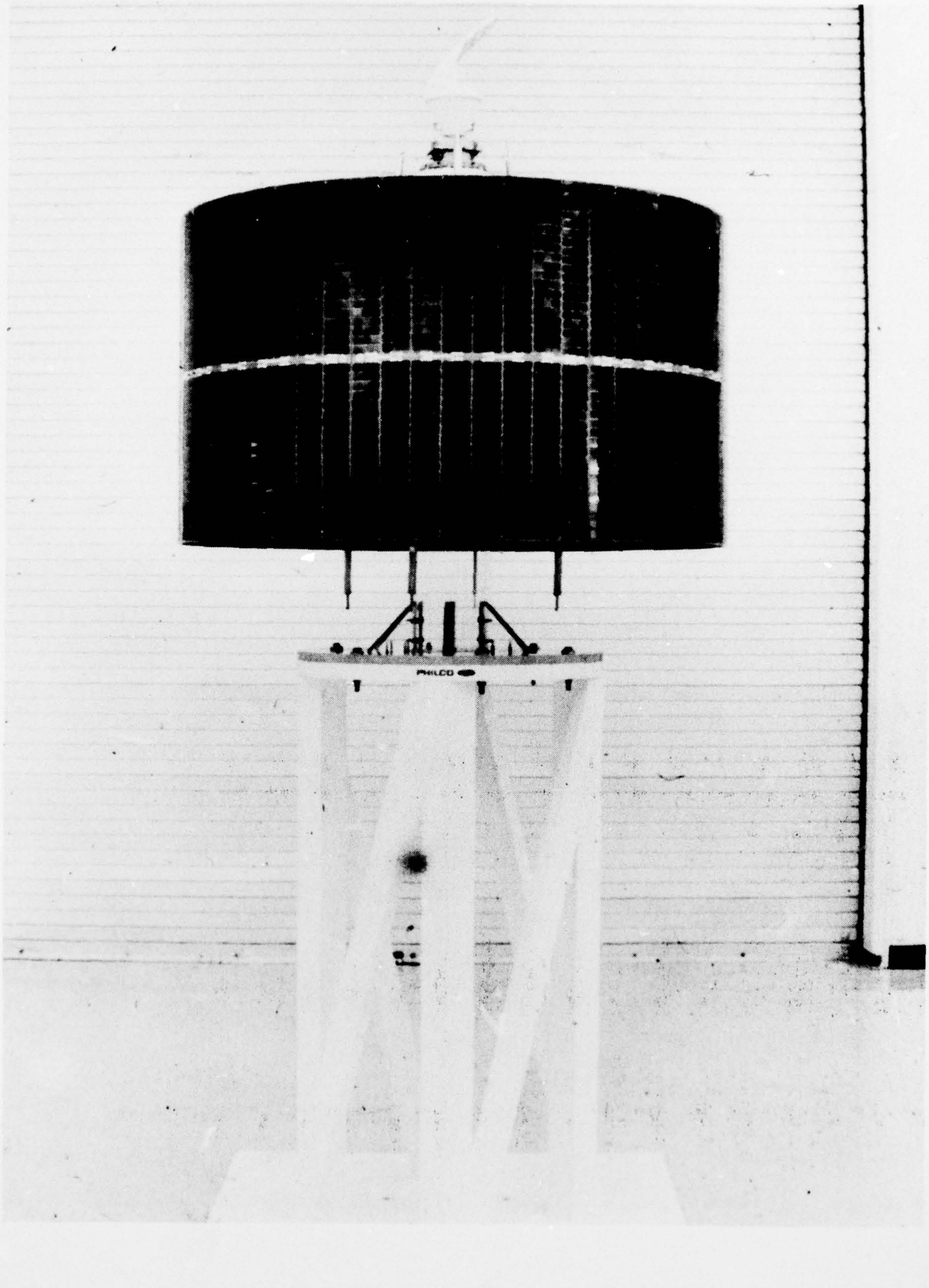


Figure 18. SKYNET Satellite in Test Configuration

5.3 Test Enclosure and Setup. The FREME building is a large hangar-like building constructed almost entirely of wood, with a curved roof sloping from the ground on 2 sides to a ridge-pole at the center about 100 feet above the floor. The floor is about 100 feet x 125 feet; the major test area is an 80 feet x 80 feet wooden floor, which has in turn been covered by a 4-5 inch layer of sand. The rest of the area has either concrete slab or gravel surfaces. There is neither building air conditioning nor humidity control, while heating is provided by 2 large gas heaters (blowers) at one end of the building. Thus, it can be seen that the test facility had a totally uncontrolled environment. As a result, it was agreed that an environmental enclosure would be constructed on a concrete pad at one end of the FREME. This enclosure was a wooden-framed octagonal shell covered with plastic sheeting (see Figures 19 and 20). A humidity recorder and a de-humidifier were kept operational during all tests to measure and reduce to acceptable levels the local humidity. The de-humidifer exhaust hose can be seen exiting the enclosure in the lower left corner of Figure 20. A simple wooden scaffold was constructed by HDL to provide easy test-personnel access to the elevated test specimen (see Figure 19). For the first test sequence, this enclosure was also covered by a copper screening, which was appropriately grounded. This had to be removed, however, as it occupied too large a solid angle and thus adversely affected other tests being carried out on the main sand-covered floor area.

5.4 Fixturing for EWR Tests. The EWR photon tests were held at PI, San Leandro, California, about 35 miles from WDL's Palo Alto facility. Because of this proximity, it was decided that the regular satellite handling dolly (which is partially visible in Figure 5) could be used to minimize the need for additional new fixturing to support these tests. The SKYNET was trucked to and from PI in this dolly, and the dolly was used as a holding/positioning fixture for all the pretest preparations. A special fiberglass test adapter (or spool) was made for the ABM-end of the satellite. Inside the chamber, the satellite was suspended (with its spin axis horizontal) from an MRC trapeze bar, via two rope loops: one around the forward v-band clamp ring, and the other around the fiberglass spool mentioned above. To transfer the satellite from its handling dolly, a fork lift was used to first suspend the satellite (with its spin axis horizontal) from its regular handling sling. The fork lift was then used to move the suspended satellite into the chamber, where the satellite suspension was transferred to the MRC trapeze. This trapeze could be manually rotated, from outside the chamber without breaking vacuum, so that the satellite could be irradiated either end-on (MDA end) or side-on.

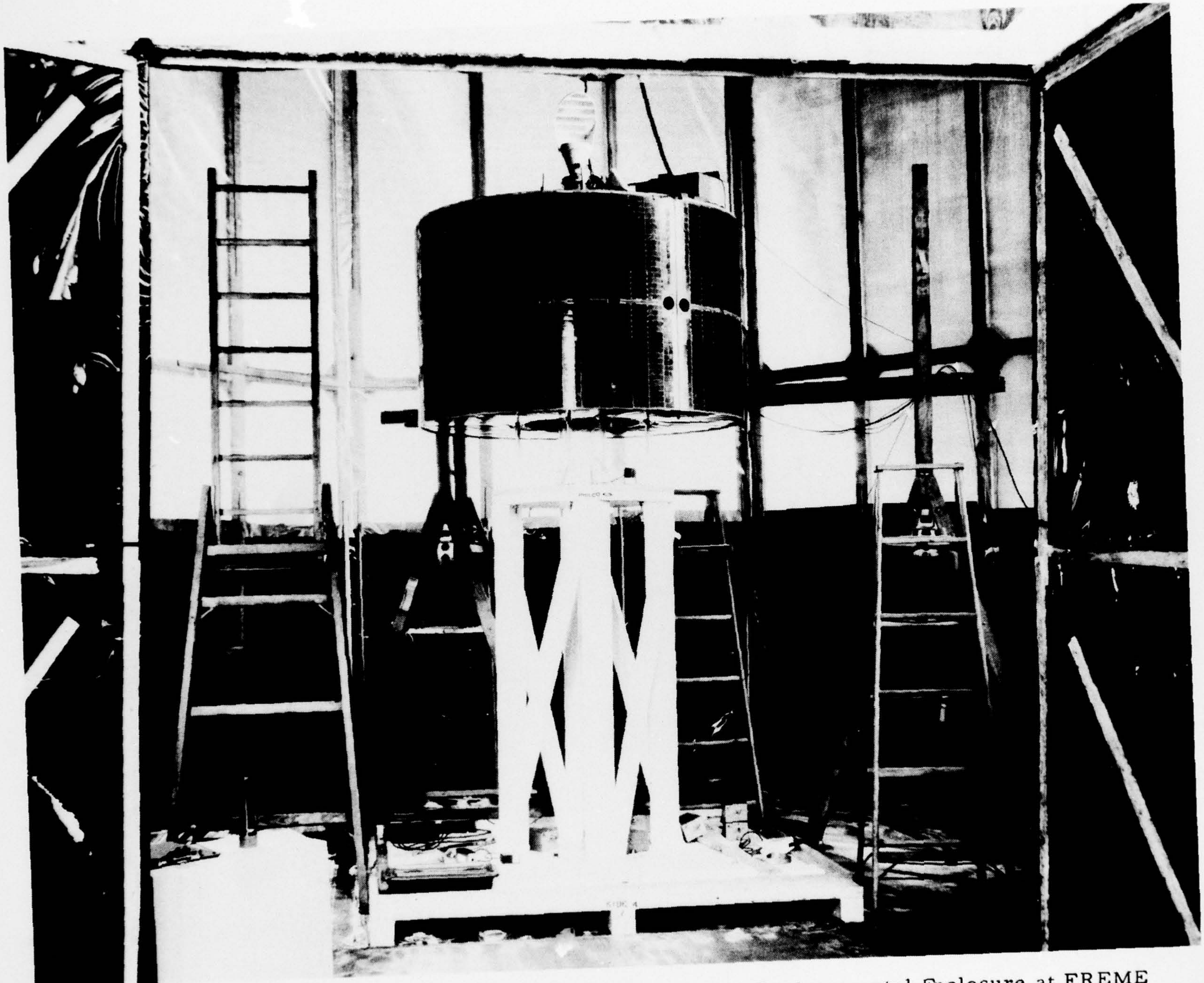


Figure 19. SKYNET Satellite Test Configuration Within Environmental Enclosure at FREME

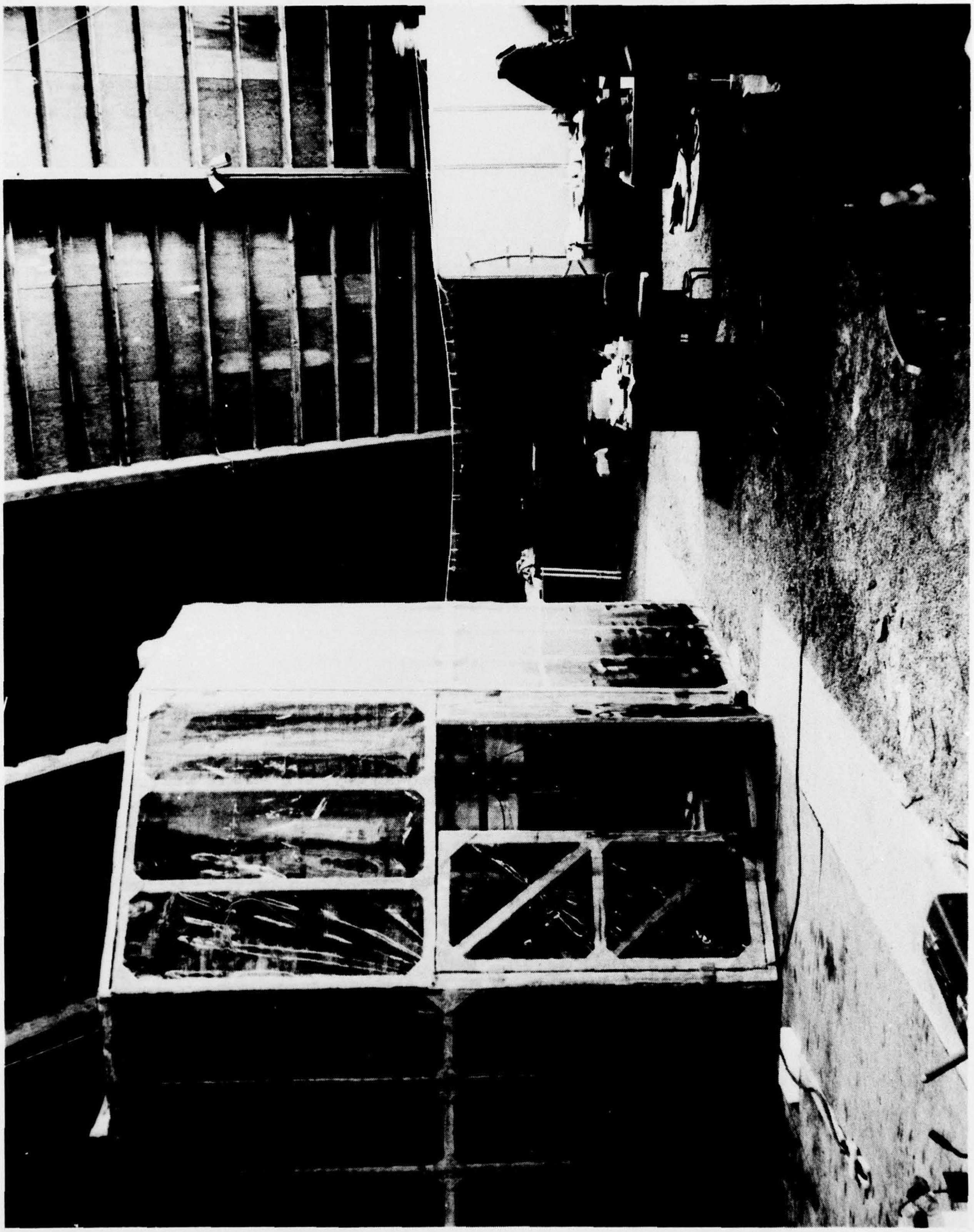


Figure 20. FREME Environmental Enclosure for SKYNET Current-Injection Testing

6.0 SKYNET TEST SCHEDULE

The initial C-I test plan was to accomplish all satellite modifications and ready all fixturing during the last 4 months of 1974. The satellite was to be shipped to FREME in Janaury, 1975, with three test sequences initially scheduled for February, April and June, 1975. The satellite modifications and fixturing were completed ahead of schedule and the satellite was shipped in late December, 1974. A total of 6 test sequences were carried out by or for HDL, with one or more WDL satellite support personnel providing support, during the following time periods:

Sequence No.	Dates
1	18-28 February 1975
2	7-18 April 1975
3	7 July – 15 August 1975*
4	8-26 September 1975
5	a) 12 November 1975**
	b) 1-19 December 1975
6	15 November - 17 December 1976

*This sequence was not continuous.

**A short preliminary checkout of modified pulsers.

Sequences 1 through 5 were carried out by HDL personnel under the personal direction of John Rosado of HDL (see References 8-9). Sequence 6 was carried out by Vasco Martins, XRI Company, under contract to HDL (see Reference 10).

A paper summarizing the Skynet C-I tests was presented by Martins and Rosado at the 1977 IEEE Conference on Nuclear and Space Radiation Effects (Reference 12), and will be published in the IEEE Conference Proceeding in December, 1977.

The EWR tests with SKYNET qualification model satellite were conducted by MRC, with IRT and Ford Aerospace support, at PI during the period 1 Nov-2 Dec 1977. In addition to the extensive series of tests in which the satellite was irradiated with an x-ray pulse, two additional series were run, with some sensors installed to characterize the structural and cable responses when:

a) The satellite was sprayed with electrons at intensities characteristic of the plasma at synchronous orbit. The electron accelerating potentials were varied from a few kilovolts to 15 kv, charging the thermal blanket (end-on illumination) or the solar panels (side-on illumination) sufficient to produce discharges. The structural/cable currents produced by such discharges were recorded.

b) The satellite was precharged by electrons, with the electron gun shut down 30 seconds prior to satellite irradiation with the OWL II x-ray pulse. These synergistic tests provide data on the effect of natural plasma precharging on the satellite SGEMP response.

Results of the Nov-Dec 1977 test series will be forthcoming.

7.0 REFERENCES

Reference 1 through 6 refer to papers presented at the AEC/DNA TREE/SGEMP Symposium, Los Alamos, New Mexico, 14-17 January 1975, and subsequently published in the Proceedings, DNA 3691P.

1. "Skynet SGEMP Program", J. A. Rosado and D. R. McMorrow, pp 543-552.

2. "Current Injection as a Means of Simulating Photo-Electron Emission", A. J. Woods and T. N. Delmer, pp 553-557.

3. "Current Injection Testing of the Skynet I Satellite", T. A. Tumolillo, pp 559-570.

4. "Pulser Developments for Current Injection", C. H. Jones, Jr., J. T. Naff and W. F. Crewson, pp 571-577.

5. "Fiber Optic Data Acquisition System for IEMP/SGEMP Testing", J. C. Blackburn and R. D. Genuario, pp 579-585.

6. "Impedance Asymmetry of Honeycomb Materials", J. Beilfuss, J. Dando and B. Broulik, pp 587-595.

7. "Skynet Program Current-Injection Program", T. A. Tumolillo et al, Parts I, II, III and IV, Intel-RT-8121-007.

8. "Skynet Current-Injection Interim Data Report", F. King and J. Rosado, HDL Internal Unpublished Memorandum M-230-76-2.

9. "Skynet Current-Injection: A Summary of Experimental Techniques", J. Rosado, F. King and H. Bruns, HDL Internal Unpublished Memorandum M-230-76-1.

10. "Current Injection Tests and Analyses on the Skynet Satellite and Its Model", V. C. Martins, HDL CR-78-178-1.

11. "Meeting on Skynet", I.E.E. Conference Publication No. 63, London, England, 20 April 1970. (These proceedings present a total of 27 papers given at the 1970 London meeting, covering all aspects of the Skynet system.)

12. "Theoretical and Measured Responses on the Skynet Satellite for Simulated SGEMP Conditions", V. C. Martins and J. A. Rosado, 1977 IEEE Conference on Nuclear and Space Radiation Effects, Williamsburg, VA, 12-15 July 1977.